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Malamut et al.

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(45) **Date of Patent: May 6, 2025**

(54) **RESTORING FROM A TEMPORARY BACKUP TARGET IN AN INTELLIGENT DESTINATION TARGET SELECTION SYSTEM FOR REMOTE BACKUPS**

(71) Applicant: **Dell Products L.P.**, Round Rock, TX (US)

(72) Inventors: **Mark Malamut**, Aliso Viejo, CA (US); **Jennifer M. Minarik**, Zionsville, IN (US); **Brian E. Freeman**, Golden, CO (US)

(73) Assignee: **Dell Products L.P.**, Round Rock, TX (US)

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(22) Filed: **Apr. 20, 2023**

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US 2024/0020200 A1 Jan. 18, 2024

Related U.S. Application Data

(63) Continuation-in-part of application No. 18/174,488, filed on Feb. 24, 2023, which is a continuation-in-part of application No. 17/863,048, filed on Jul. 12, 2022, now Pat. No. 11,880,281.

(51) **Int. Cl.**
G06F 11/14 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 11/1435*** (2013.01); ***G06F 11/1464*** (2013.01); ***G06F 11/1466*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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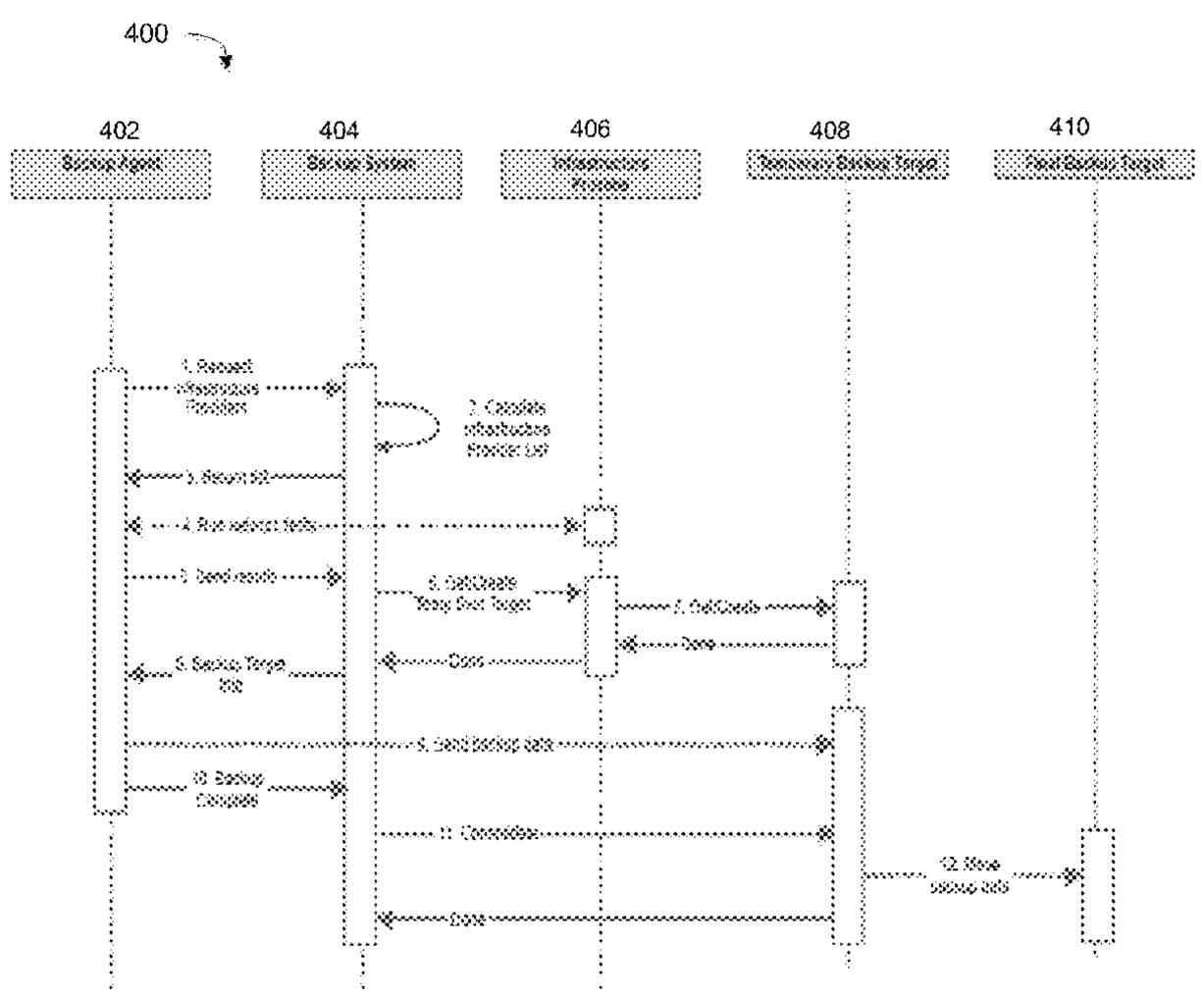
Primary Examiner — Brian R Peugh
(74) *Attorney, Agent, or Firm* — Staniford Tomita LLP

(57) **ABSTRACT**

A system that automatically determines ideal temporary backup targets (TBTs) to store and restore backup data. For multiple TBTs, backup data is saved with location information to restore incremental backup data from these multiple targets. Hashes of each file are stored in a Merkle tree to enable data restore workflows and minimizing an amount of storage required to hold backup data. The lowest tree level comprises hashes of the backup data chunks, and higher levels contain hashes of the next lower levels. A backup target location value is added to non-data chunk hash records in the higher levels to identify where any piece of backup data is located so that restore operations can occur when the backup data is spread across multiple backup targets.

20 Claims, 14 Drawing Sheets



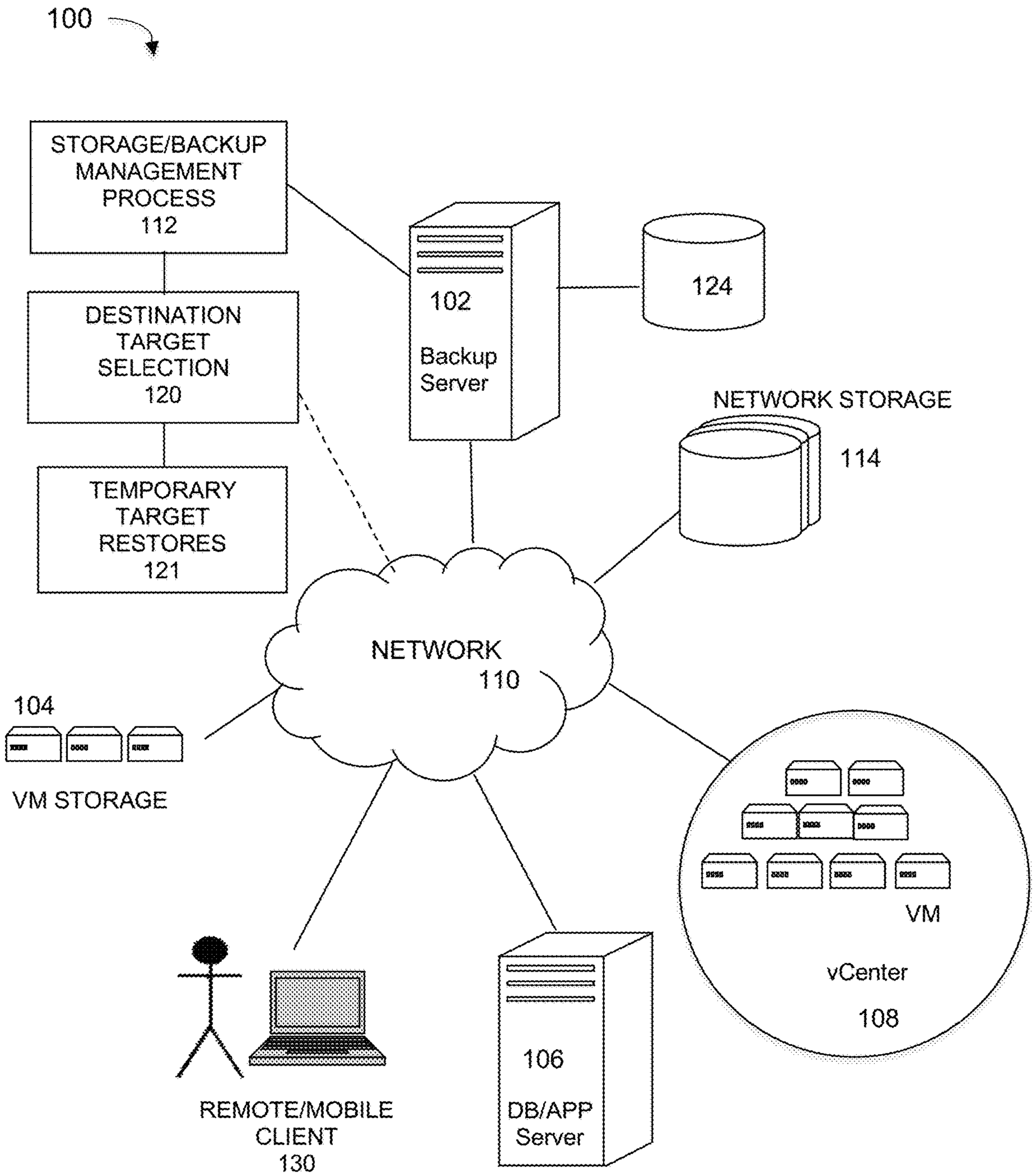

100
STORAGE/BACKUP MANAGEMENT PROCESS 112
DESTINATION TARGET SELECTION 120
TEMPORARY TARGET RESTORES 121
102
Backup Server
124
NETWORK STORAGE
114
NETWORK 110
104
VM STORAGE
VM
vCenter
108
106
DB/APP Server
REMOTE/MOBILE CLIENT 130

FIG. 1

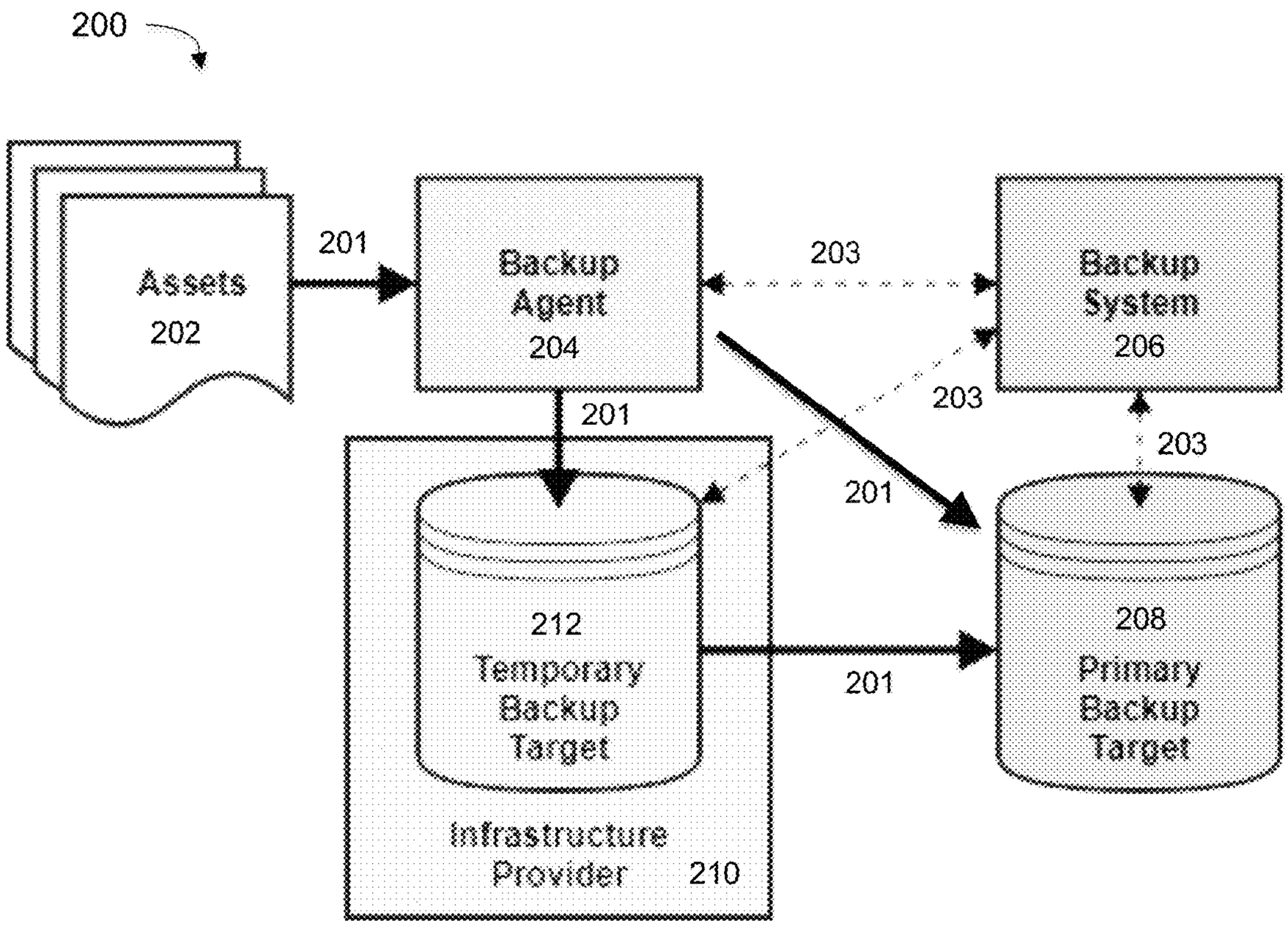

200
Assets
202
201
Backup
Agent
204
203
Backup
System
206
201
203
203
201
212
Temporary
Backup
Target
201
208
Primary
Backup
Target
Infrastructure
Provider
210

FIG. 2

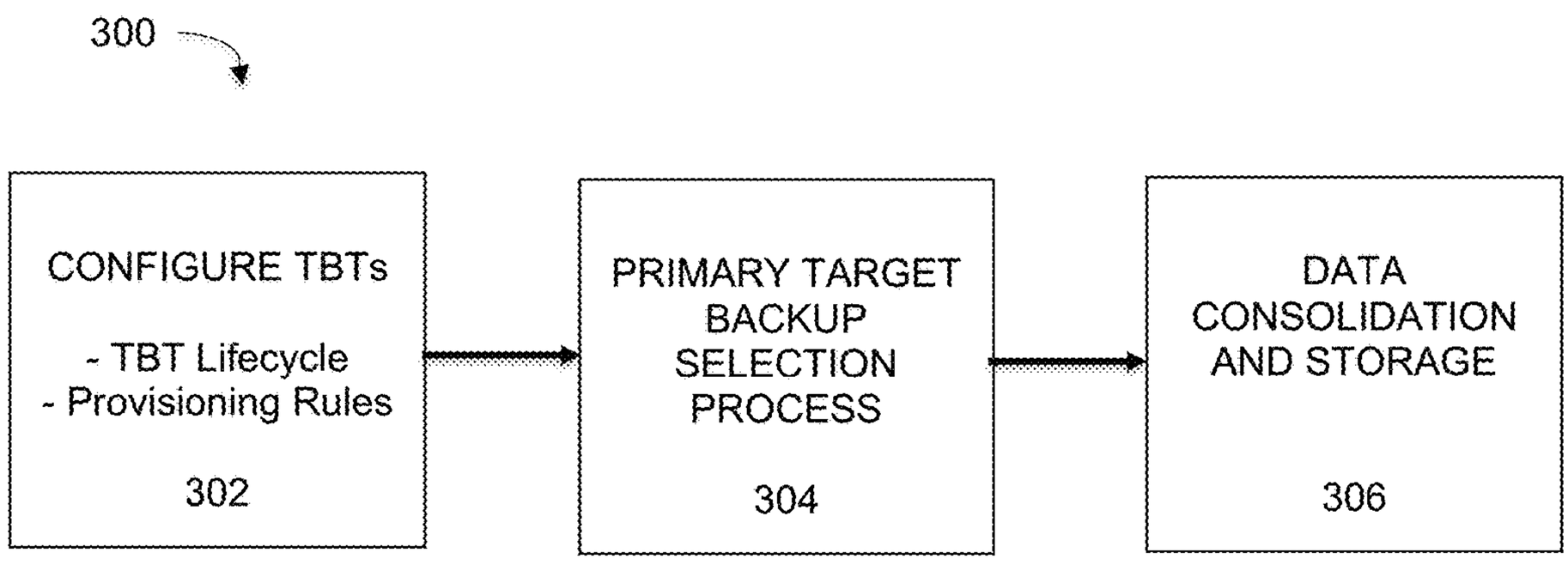

300
CONFIGURE TBTs
- TBT Lifecycle
- Provisioning Rules
302
PRIMARY TARGET
BACKUP
SELECTION
PROCESS
304
DATA
CONSOLIDATION
AND STORAGE
306

FIG. 3

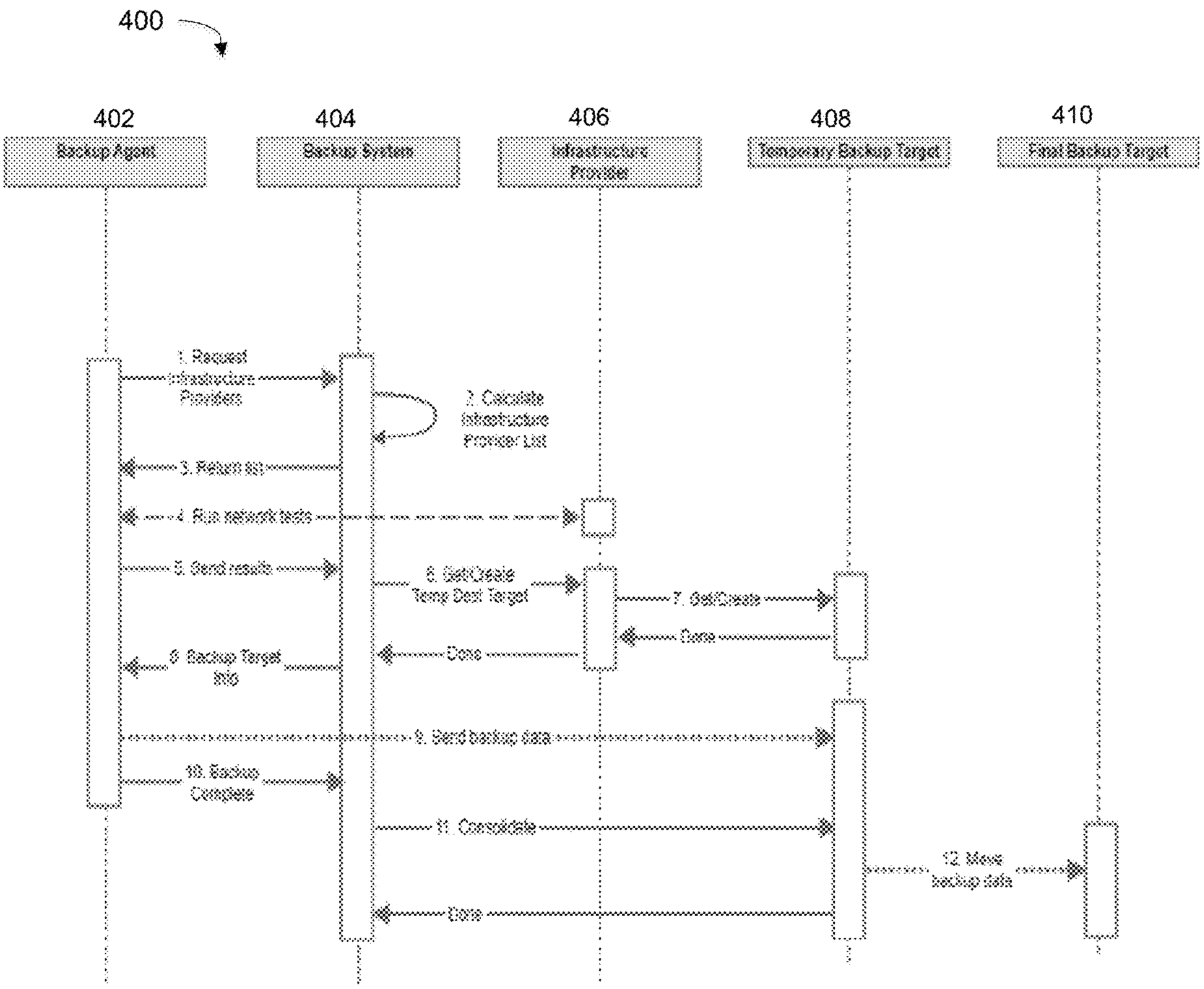

400
402
Backup Agent
404
Backup System
406
Infrastructure Provider
408
Temporary Backup Target
410
Final Backup Target
1. Request Infrastructure Providers
2. Calculate Infrastructure Provider List
3. Return list
4. Run network tests
5. Send results
6. GetCreds Temp Dest Target
7. GetCreds
Done
Done
8. Backup Target Info
9. Send backup data
10. Backup Complete
11. Consolidate
12. Move backup data
Done

FIG. 4

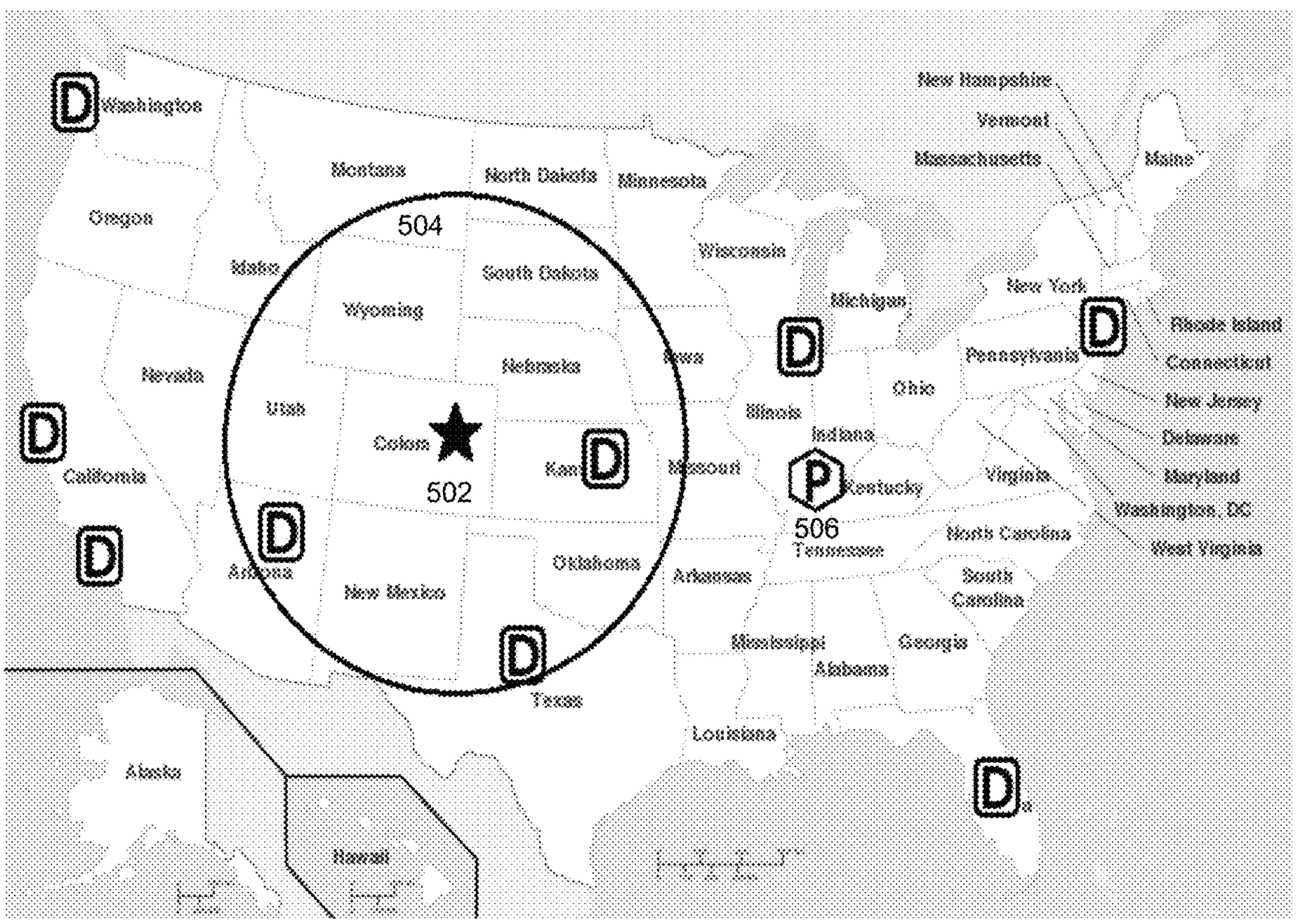

500
504
502
506
D
P
Washington
Oregon
California
Montana
North Dakota
Minnesota
South Dakota
Wyoming
Nebraska
Utah
Nevada
Colorado
Kansas
Missouri
Arizona
New Mexico
Oklahoma
Texas
Arkansas
Illinois
Michigan
Wisconsin
Iowa
Indiana
Ohio
Kentucky
Tennessee
Mississippi
Alabama
Georgia
Louisiana
South Carolina
North Carolina
Virginia
Pennsylvania
New York
New Hampshire
Vermont
Massachusetts
Maine
Rhode Island
Connecticut
New Jersey
Delaware
Maryland
Washington, DC
West Virginia
Alaska
Hawaii

FIG. 5

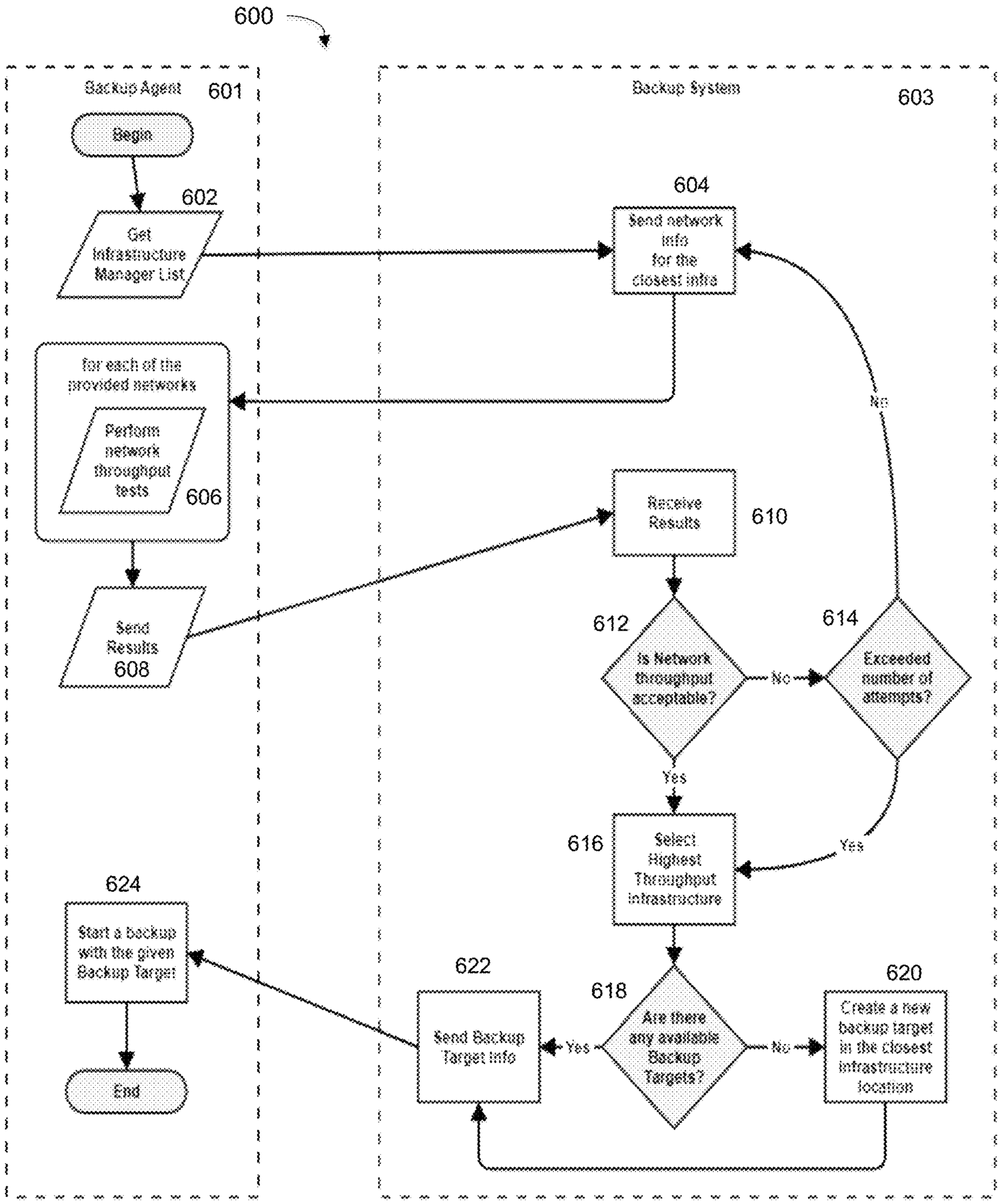

600
Backup Agent
601
Begin
602
Get Infrastructure Manager List
for each of the provided networks
Perform network throughput tests
606
Send Results
608
Backup System
603
604
Send network info for the closest infra
No
Receive Results
610
612
Is Network throughput acceptable?
No
614
Exceeded number of attempts?
Yes
Yes
616
Select Highest Throughput Infrastructure
618
Are there any available Backup Targets?
Yes
No
620
Create a new backup target in the closest infrastructure location
622
Send Backup Target info
624
Start a backup with the given Backup Target
End

FIG. 6

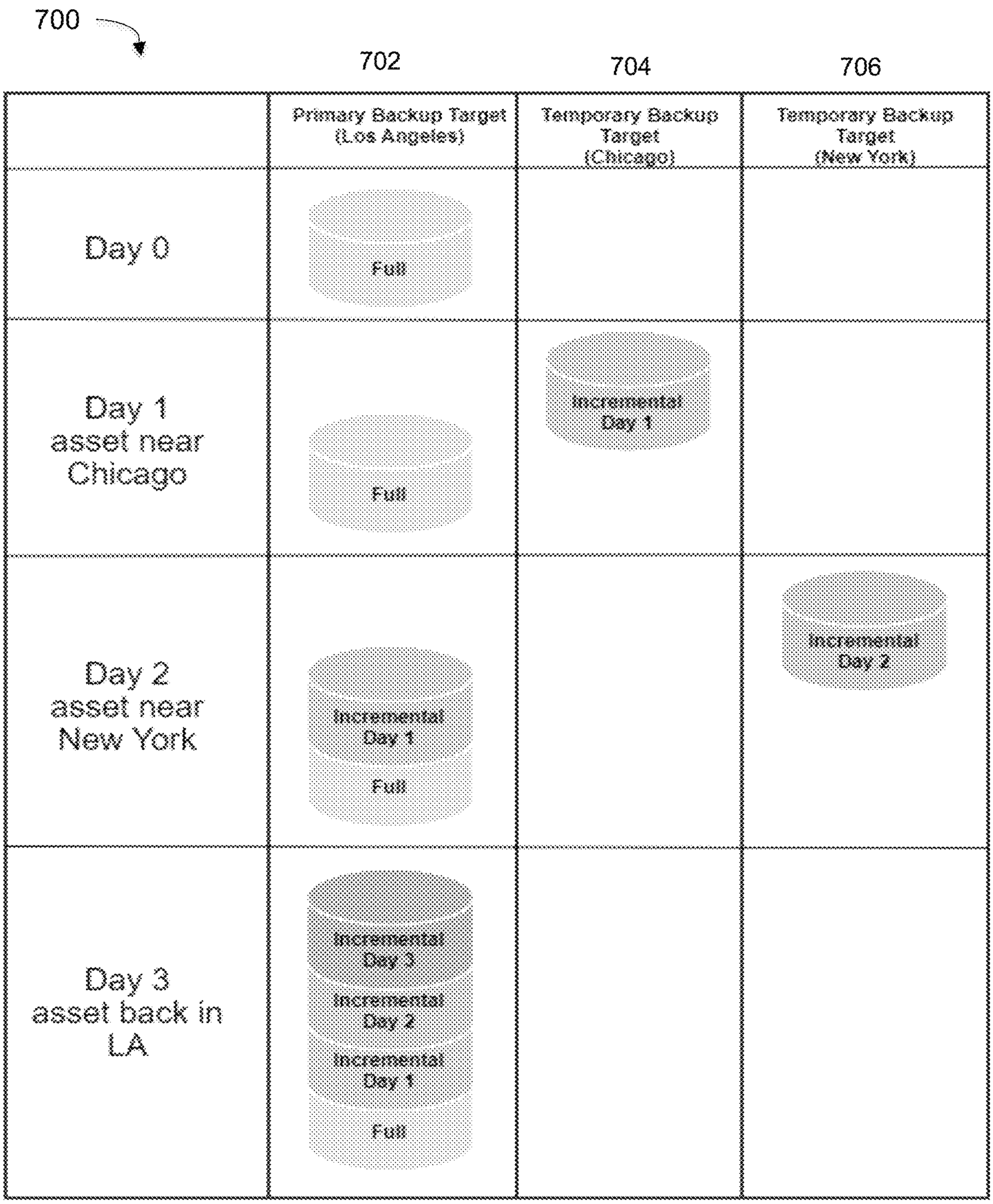

700
702
704
706
Primary Backup Target (Los Angeles)
Temporary Backup Target (Chicago)
Temporary Backup Target (New York)
Day 0
Full
Day 1 asset near Chicago
Full
Incremental Day 1
Incremental Day 2
Day 2 asset near New York
Incremental Day 1
Full
Day 3 asset back in LA
Incremental Day 3
Incremental Day 2
Incremental Day 1
Full

FIG. 7

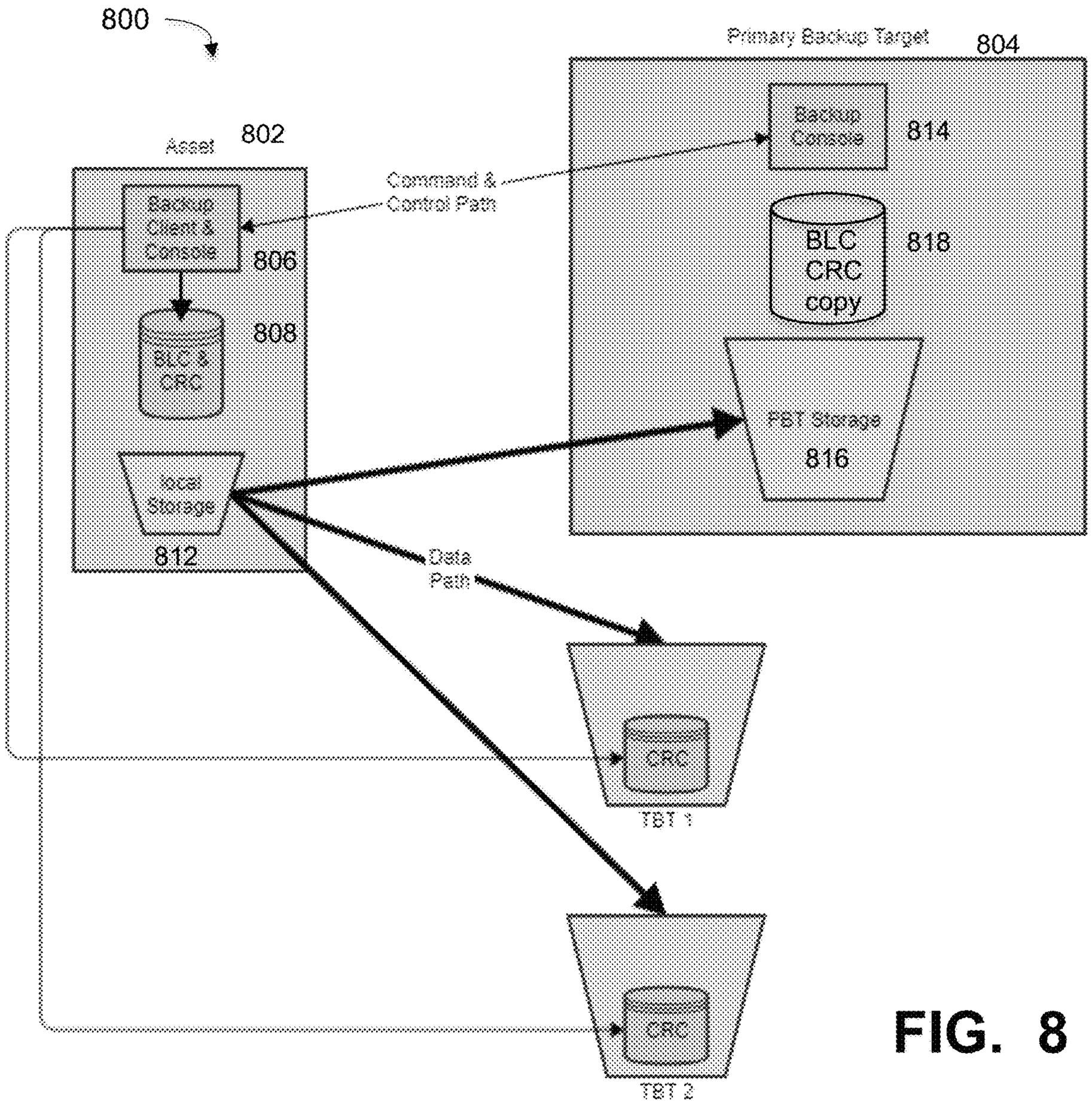


FIG. 8

900

Date 901	Location 902
6/15/2022	PBT:ppdm_irvine_prod.dell.com
6/16/2002	AWS:us_east_1a@S3:userSmith002:2022.06.16
6/17/2022	AWS:us_east_1a@S3:userSmith002:2022.06.17
6/21/2002	AWS:ap_east_1@S3:userSmith002:2022.06.21

FIG. 9

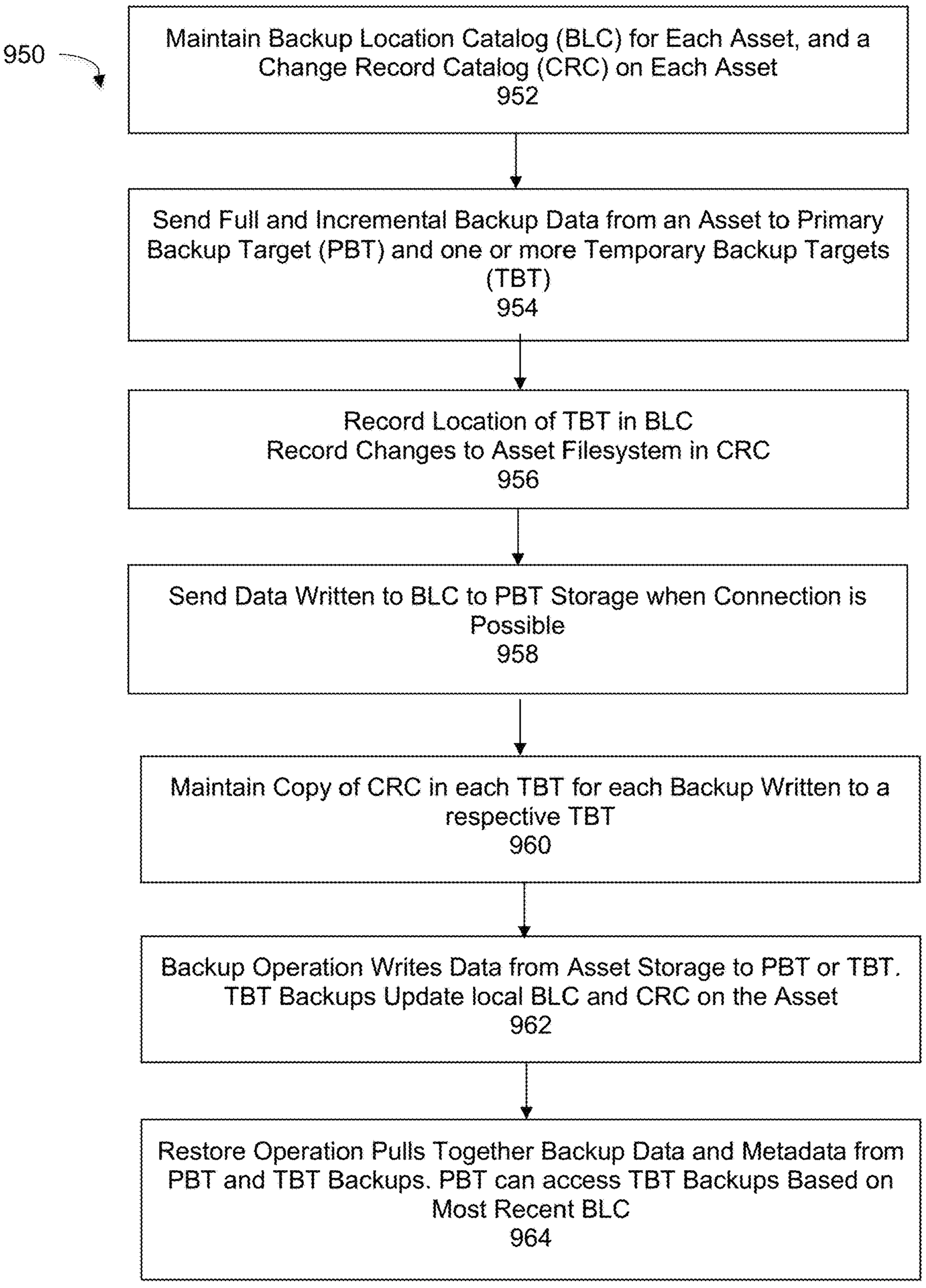
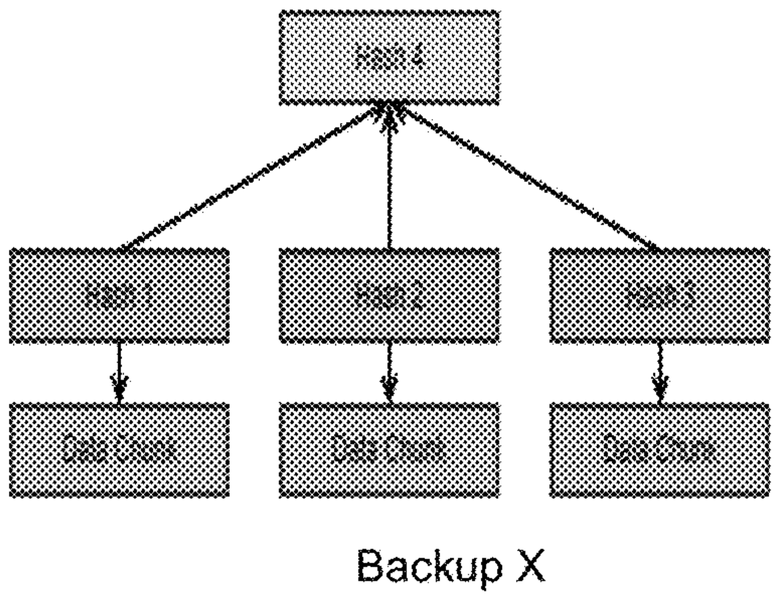
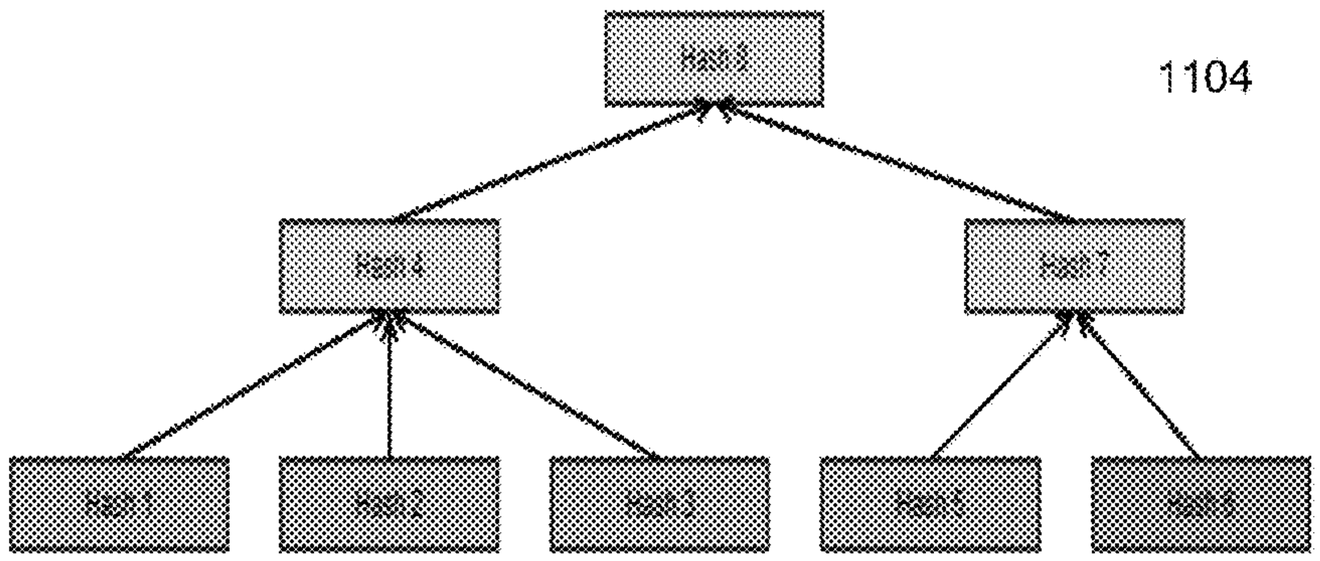

950
Maintain Backup Location Catalog (BLC) for Each Asset, and a Change Record Catalog (CRC) on Each Asset
952
Send Full and Incremental Backup Data from an Asset to Primary Backup Target (PBT) and one or more Temporary Backup Targets (TBT)
954
Record Location of TBT in BLC
Record Changes to Asset Filesystem in CRC
956
Send Data Written to BLC to PBT Storage when Connection is Possible
958
Maintain Copy of CRC in each TBT for each Backup Written to a respective TBT
960
Backup Operation Writes Data from Asset Storage to PBT or TBT. TBT Backups Update local BLC and CRC on the Asset
962
Restore Operation Pulls Together Backup Data and Metadata from PBT and TBT Backups. PBT can access TBT Backups Based on Most Recent BLC
964

FIG. 10



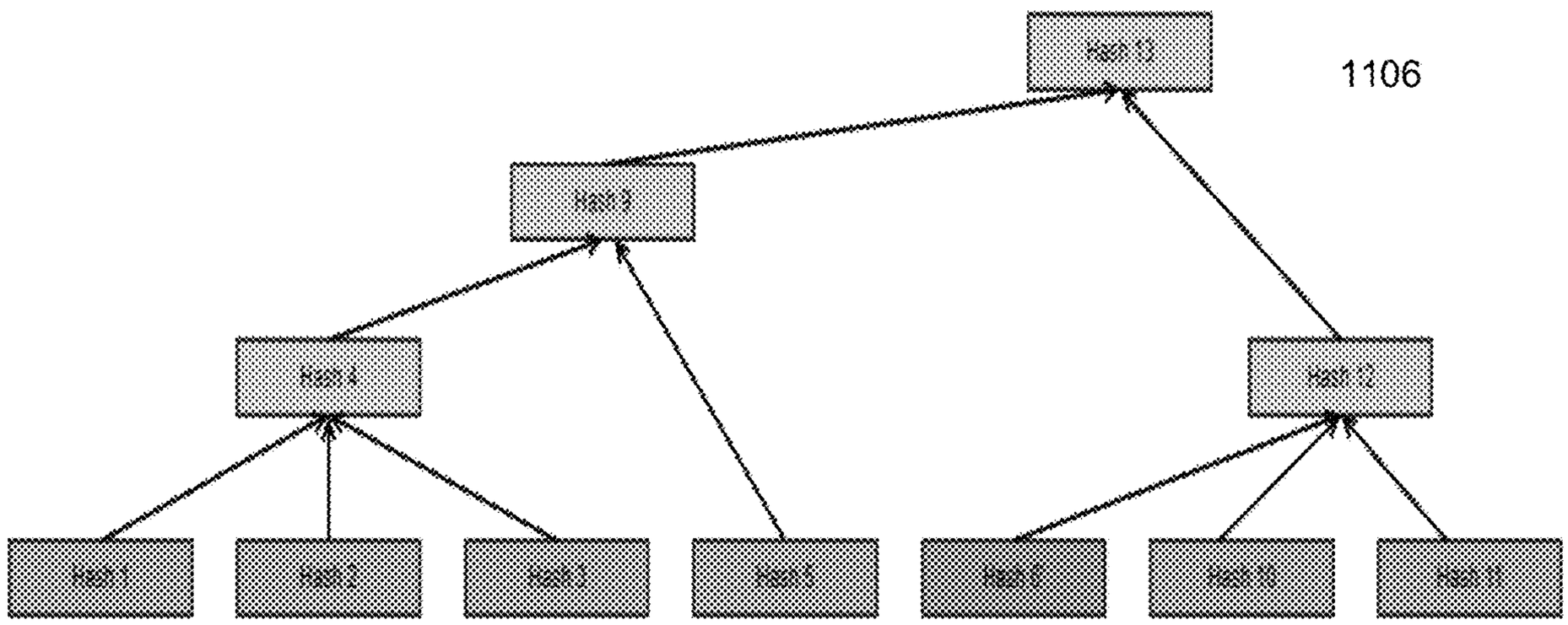
1102

Backup X



1104

Backup X + 1



1106

Backup X + 2

FIG. 11

1202

Backup	Backup Root Hash	Chunk Hashes	Intermediate Hashes
X	4	1 2 3	N/A
X + 1	8	1 2 3 5 6	4 7
X + 2	13	1 2 3 5 6' 10 11	4 9 12

FIG. 12

1302

Location ID	Backup Target Type	Backup Target Location	Backup URL	$/GET	$/MB
0	Primary	Home	backup.isg.dell.com	$0	$0
1	Temporary	Virginia, USA	aws::US-EAST-1::8ca0ccd2-5c47-49d9-817e-6a43b695c50a	$0.004	$0.09/GB
2	Temporary	London, UK	aws::EU-WEST-2::7bf0ccd2-5c47-49d9-817e-6a43b695c99e	$0.004	$0.09/GB

FIG. 13

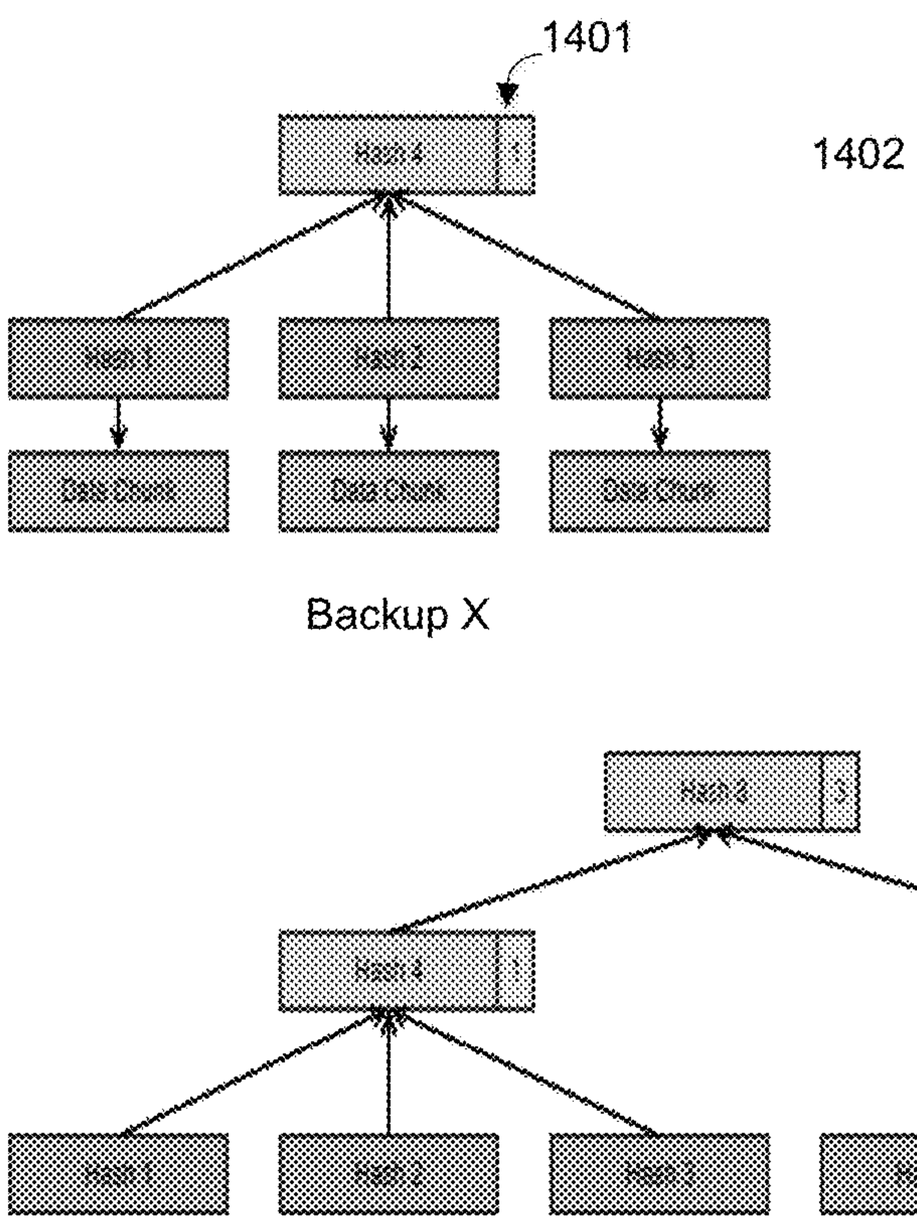


FIG. 14

1502

Backup	Backup Root Hash	Chunk Hashes	Intermediate Hashes
X	4	1 2 3	N/A
X + 1	8	1 2 3 5 6	4 7
X + 2	14	1 2 3 5 6' 11 12	4 9 10 13

FIG. 15

1702

Backup	Root Hash Location Value	Backup URLs
X	1	backup.isg.dell.com aws::US-EAST-1::8da0ccd2-5c47-49d9-817e-6a43b695c50a
X + 1	3	backup.isg.dell.com aws::US-EAST-1::8da0ccd2-5c47-49d9-817e-6a43b695c50a
X + 2	7	backup.isg.dell.com aws::US-EAST-1::8da0ccd2-5c47-49d9-817e-6a43b695c50a aws::EUROPE-2::7bl0ccd2-5c47-49d9-817e-6a43b695c99e

FIG. 17

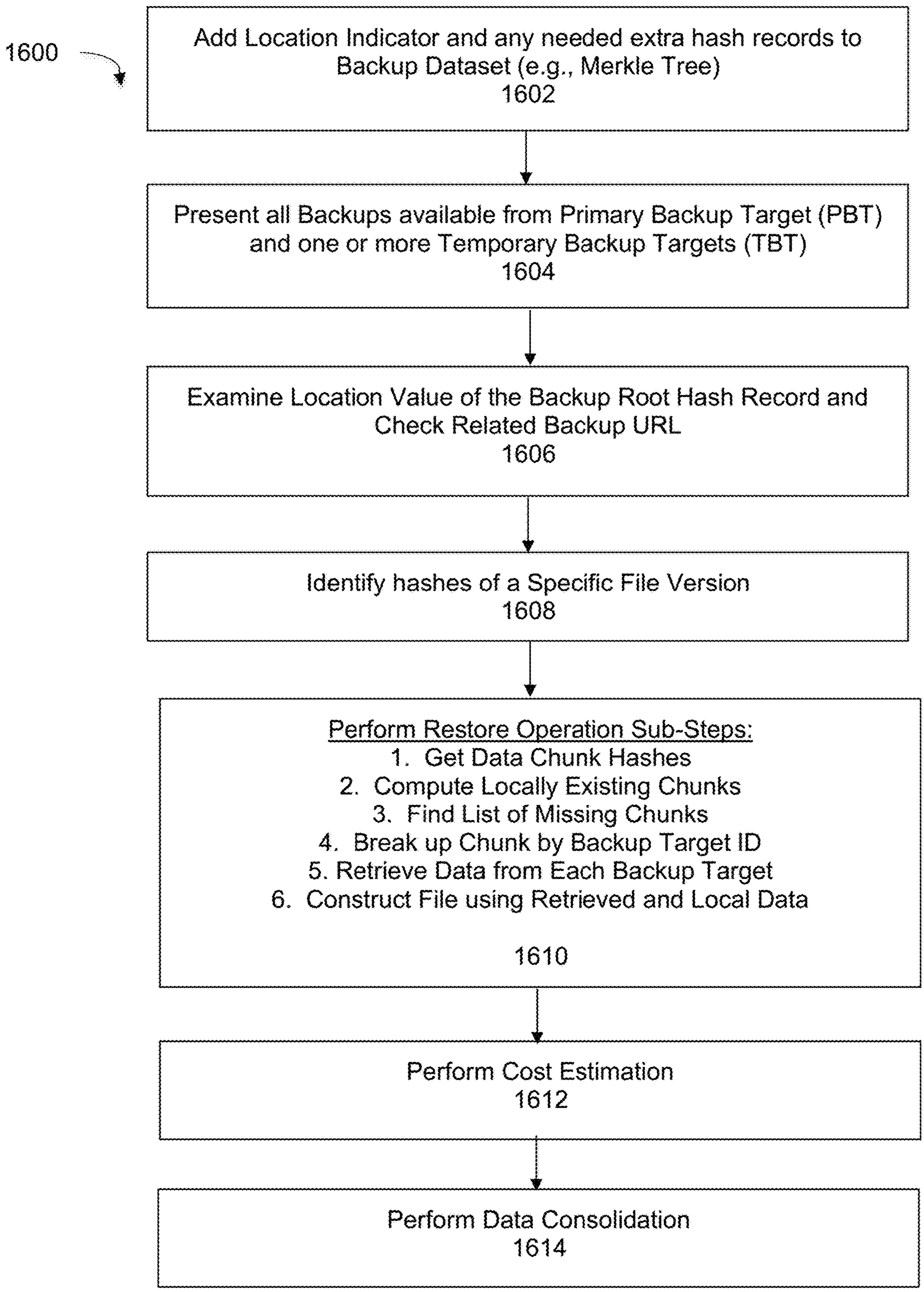

1600
Add Location Indicator and any needed extra hash records to Backup Dataset (e.g., Merkle Tree)
1602
Present all Backups available from Primary Backup Target (PBT) and one or more Temporary Backup Targets (TBT)
1604
Examine Location Value of the Backup Root Hash Record and Check Related Backup URL
1606
Identify hashes of a Specific File Version
1608
Perform Restore Operation Sub-Steps:
1. Get Data Chunk Hashes
2. Compute Locally Existing Chunks
3. Find List of Missing Chunks
4. Break up Chunk by Backup Target ID
5. Retrieve Data from Each Backup Target
6. Construct File using Retrieved and Local Data
1610
Perform Cost Estimation
1612
Perform Data Consolidation
1614

FIG. 16

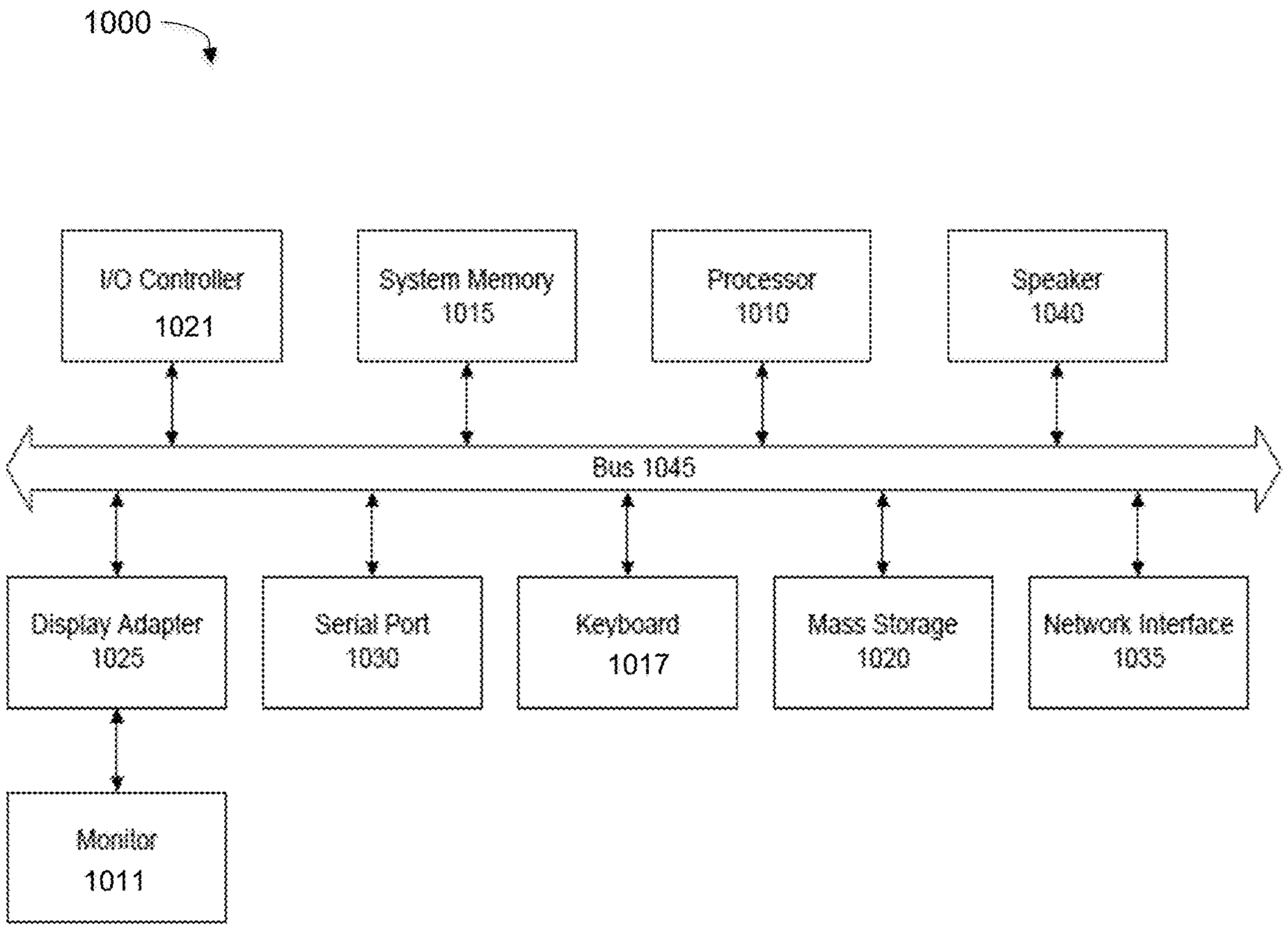

1000
I/O Controller
1021
System Memory
1015
Processor
1010
Speaker
1040
Bus 1045
Display Adapter
1025
Serial Port
1030
Keyboard
1017
Mass Storage
1020
Network Interface
1035
Monitor
1011

FIG. 18

RESTORING FROM A TEMPORARY BACKUP TARGET IN AN INTELLIGENT DESTINATION TARGET SELECTION SYSTEM FOR REMOTE BACKUPS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a Continuation-In-Part application and claims priority to U.S. patent application Ser. No. 18/174,488 filed on Feb. 24, 2023 and entitled "Intelligent Destination Target Selection for Remote Backups with Awareness of Temporary Backup Target for Data Restores," now U.S. Pat. No. 12,026,385 which in turn is a Continuation-In-Part application and claims priority to U.S. patent application Ser. No. 17/863,048 filed on Jul. 12, 2022 and entitled "Intelligent Destination Target Selection for Remote Backups," now U.S. Pat. No. 11,455,109 both of which are assigned to the assignee of the present application, and which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

This invention relates generally to data backup systems, and more specifically to restoring data from a temporary backup target selected by an intelligent remote backup system.

BACKGROUND

Backup software is used by large organizations to store their data for recovery after system failures, routine maintenance, archiving, and so on. Backup sets are typically taken on a regular basis, such as hourly, daily, weekly, and so on, and can comprise vast amounts of information. In today's world, many of a company's digital assets may be constantly moving and not always located in the same geographic location. Some examples include an employee who is constantly traveling with their company laptop, a cloud deployed virtual machine (VM) where the location is determined at deploy time, or an application or asset that resides in a vehicle that is constantly changing locations.

Creating backups of these types of assets can be challenging because of this mobility and the various network connections the device hosting these assets might have available. In many situations the network connection between the asset and a traditional backup system can be very poor due to connectivity issues. In this case, completing a backup might be very time consuming, or even take more time than available to complete. This issue can quickly become critical if the backup system is unable to successfully complete a backup over long periods of time, which can put the company at a high risk for data loss.

A primary flaw in traditional backup systems is that they typically have a fixed backup target to which to send the backup data. In addition, changing the backup target typically incurs the high cost of creating a new full backup, as opposed to a more customary incremental backup. Another limitation is that most backup systems have one primary backup target defined for multiple assets, and do not provide the flexibility to dynamically pick a backup target based on a "best available" algorithm that may result in different targets based on the location of the asset.

Present systems typically require a user to manually deploy backup storage targets and then configure backup policies to then use these fixed targets. In addition they need to manually assign the assets to policies with designated

storage. Every time an asset changes its geographic location, the protection policy for that asset needs to be manually updated to reconfigure it to use a different fixed backup target. Changing the backup target incurs the cost of a new full backup, which can have a huge performance and time implication for large assets. Additionally, if the backup target and its infrastructure is not owned by the asset owner, the company or other responsible party for the asset will incur additional costs for using the backup infrastructure.

Methods have been developed to address this issue by providing temporary backup targets to hold backup data when an asset stores some incremental backups on an alternate backup target. In such systems, assets typically cannot restore data until the data is consolidated to the primary backup target. It is therefore desirable to enable data restores from backup data that is stored in either (or both) the primary and temporary backup targets.

The subject matter discussed in the background section should not be assumed to be prior art merely as a result of its mention in the background section. Similarly, a problem mentioned in the background section or associated with the subject matter of the background section should not be assumed to have been previously recognized in the prior art. The subject matter in the background section merely represents different approaches, which in and of themselves may also be inventions. EMC, Data Domain and Data Domain Restorer are trademarks of DellEMC Corporation.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following drawings like reference numerals designate like structural elements. Although the figures depict various examples, the one or more embodiments and implementations described herein are not limited to the examples depicted in the figures.

FIG. **1** is a diagram of a network implementing an intelligent destination target selection process, under some embodiments.

FIG. **2** is a block diagram of illustrating functional components of an intelligent destination target selection process, under some embodiments.

FIG. **3** is a diagram illustrating some main components of the deployment and use of a temporary backup target, under some embodiments.

FIG. **4** is a state transition diagram that illustrates the process of selecting an optimal backup storage target and transmitting the backup data and consolidating data to the primary target, under some embodiments.

FIG. **5** illustrates the selection of an infrastructure provider networks by a backup system for an asset, in an example embodiment.

FIG. **6** is a flow diagram illustrating interactions between a backup agent and backup system when selecting an optimal backup target, under some embodiments.

FIG. **7** illustrates an example data flow between the asset, temporary backup target, and the final primary backup target for a consolidation operation, under some embodiments.

FIG. **8** illustrates the use of a Backup Location Catalog (BLC) and Change Record Catalog (CRC) for awareness of temporary backup targets for data restores, under some embodiments.

FIG. **9** is a table **900** that illustrates a portion of a backup location catalog, under an example embodiment.

FIG. **10** is a flowchart that illustrates a method of providing intelligent target selection for portable assets using awareness of temporary backup targets, under some embodiments.

FIG. **11** illustrates some example Merkle tree representations of different backups with no temporary backup target, under some embodiments.

FIG. **12** is a table illustrating a tabular composition of the example Merkle trees of FIG. **11**.

FIG. **13** illustrates a table for an enhanced Merkle tree with location information, under some embodiments.

FIG. **14** shows the evolution of the Merkle trees of FIG. **11** for the case of a single file stored over three backups for an embodiment using multiple backup targets.

FIG. **15** is a table that illustrates attributes of the enhanced Merkle tree of FIG. **14** after a second subsequent backup.

FIG. **16** is a flowchart that illustrates a method of performing backup and restores using location information for temporary backup targets, under some embodiments.

FIG. **17** illustrates a table showing backup URLs related to a backup, under some embodiments.

FIG. **18** is a system block diagram of a computer system used to execute one or more software components described herein, under some embodiments.

DETAILED DESCRIPTION

A detailed description of one or more embodiments is provided below along with accompanying figures that illustrate the principles of the described embodiments. While aspects are described in conjunction with such embodiment(s), it should be understood that it is not limited to any one embodiment. On the contrary, the scope is limited only by the claims and the described embodiments encompass numerous alternatives, modifications, and equivalents. For the purpose of example, numerous specific details are set forth in the following description in order to provide a thorough understanding of the described embodiments, which may be practiced according to the claims without some or all of these specific details. For the purpose of clarity, technical material that is known in the technical fields related to the embodiments has not been described in detail so that the described embodiments are not unnecessarily obscured.

It should be appreciated that the described embodiments can be implemented in numerous ways, including as a process, an apparatus, a system, a device, a method, or a computer-readable medium such as a computer-readable storage medium containing computer-readable instructions or computer program code, or as a computer program product, comprising a computer-usable medium having a computer-readable program code embodied therein. In the context of this disclosure, a computer-usable medium or computer-readable medium may be any physical medium that can contain or store the program for use by or in connection with the instruction execution system, apparatus or device. For example, the computer-readable storage medium or computer-usable medium may be, but is not limited to, a random-access memory (RAM), read-only memory (ROM), or a persistent store, such as a mass storage device, hard drives, CDROM, DVDROM, tape, erasable programmable read-only memory (EPROM or flash memory), or any magnetic, electromagnetic, optical, or electrical means or system, apparatus or device for storing information. Alternatively, or additionally, the computer-readable storage medium or computer-usable medium may be any combination of these devices or even paper or another suitable medium upon which the program code is printed, as the program code can be electronically captured, via, for instance, optical scanning of the paper or other medium, then compiled, interpreted, or otherwise processed in a suitable manner, if necessary, and then stored in a computer memory.

Applications, software programs or computer-readable instructions may be referred to as components or modules. Applications may be hardwired or hard coded in hardware or take the form of software executing on a general-purpose computer or be hardwired or hard coded in hardware such that when the software is loaded into and/or executed by the computer, the computer becomes an apparatus for practicing the certain methods and processes described herein. Applications may also be downloaded, in whole or in part, through the use of a software development kit or toolkit that enables the creation and implementation of the described embodiments. In this specification, these implementations, or any other form that embodiments may take, may be referred to as techniques. In general, the order of the steps of disclosed processes may be altered within the scope of the embodiments.

Some embodiments involve data processing in a distributed system, such as a cloud based network system or very large-scale wide area network (WAN), and metropolitan area network (MAN), however, those skilled in the art will appreciate that embodiments are not limited thereto, and may include smaller-scale networks, such as LANs (local area networks). Thus, aspects of the one or more embodiments described herein may be implemented on one or more computers executing software instructions, and the computers may be networked in a client-server arrangement or similar distributed computer network.

Embodiments are described for a backup system in which a data asset sends its backup data to a dynamically selected backup target for remote backups and assets in motion. The selection is based on a series of attributes such as network throughput and availability. Backups which are sent to a temporary backup target are later consolidated at the assets primary backup target. The data assets may be mobile or they may reside at a single location to address network or other availability issues with any source connecting to a backup target.

FIG. **1** illustrates a computer network system that implements one or more embodiments of a network data backup system implementing an intelligent backup target selection process, under some embodiments. In system **100**, a backup server **102** executes a data storage or backup management process **112** that coordinates or manages the backup of data from one or more data sources **108** to storage devices, such as network storage **114**, client storage, and/or virtual storage devices **104**. With regard to virtual storage **104**, any number of virtual machines (VMs) or groups of VMs may be provided to serve as backup targets. For example, virtualized data center (vCenter) **108** that includes any number of VMs for target storage. The VMs or other network storage devices serve as target storage devices for data backed up from one or more data sources, such as a database or application server **106**, or the data center **108** itself, or any other data source, in the network environment.

In an embodiment, system **100** may comprise at least part of a Data Domain Restorer (DDR)-based deduplication storage system, and storage server **102** may be implemented as a DDR Deduplication Storage server provided by EMC Corporation. However, other similar backup and storage systems are also possible.

The client and server computers are coupled directly or indirectly to each other and the system resources (target storage, routers, etc.) through network **110**, which is typically a public cloud network (but may also be a private

cloud, LAN, WAN or other similar network). Network **110** provides connectivity to the various systems, components, and resources of system **100**, and may be implemented using protocols such as Transmission Control Protocol (TCP) and/or Internet Protocol (IP), well known in the relevant arts. In a cloud computing environment, network **110** represents a network in which applications, servers and data are maintained and provided through a centralized cloud computing platform.

Network elements that generate the data to be backed up are referred as backup 'clients' and backup agents deployed throughout the system perform the data backup through process **112** and backup server **102**. The data to be backed up by process **112** can be referred to as data assets and may be any appropriate data, such as database data that is part of a database management system or any appropriate application supported by server **106**.

The backup clients may be static clients that are fixed in position or location and always use a fixed network address, such as a static server (e.g., **106**), or they may be mobile clients or data sources that are dynamically deployed on demand or according to certain policies or schedules, such as virtual machines or data centers **108**. One typical example of a mobile client is a user operating a mobile computer **130** who logs in to the backup server from different locations as they move around. The term 'asset' as used herein may thus generally refer to a device that generates or processes data to be backed up, such as a server, computer, portable computer (laptop/notebook/tablet), communication device (mobile phone), or any other processing device capable of being moved and used to generate data. This term can also refer to the actual data (backup dataset) generated by the device.

The data generated or sourced by system **100** and transmitted over network **110** may be stored in any number of persistent storage locations and devices. In a backup case, the backup process **112** causes or facilitates the backup of this data to other storage devices of the network, such as network storage **114**, which may at least be partially implemented through storage device arrays, such as RAID components. In an embodiment network **100** may be implemented to provide support for various storage architectures such as storage area network (SAN), Network-attached Storage (NAS), or Direct-attached Storage (DAS) that make use of large-scale network accessible storage devices **114**, such as large capacity disk (optical or magnetic) arrays. Certain defined backup policies usually dictate which target storage devices are used for the different backup clients, and different storage targets may be used for different clients depending on client location and size/type of the backup datasets. Current backup systems typically require a user to manually deploy backup storage targets and then configure backup policies to then use these fixed targets and manually assign the assets to policies with designated target storage devices. As stated previously, every time an asset changes its location, the policy for that asset must be reconfigured to point to the primary backup target. As shown in FIG. **1**, system **100** includes an intelligent destination target selection process **120** that dynamically selects the appropriate backup target for backups from remote or mobile backup clients and data sources ('assets in motion').

Backup software vendors typically provide service under a service level agreement (SLA) that establishes the terms and costs to use the network and transmit/store data specifies minimum resource allocations (e.g., storage space) and performance requirements (e.g., network bandwidth) provided by the provider. The backup software may be any suitable backup program such as EMC Data Domain, Avamar, and so on. In cloud networks, it may be provided by a cloud service provider server (e.g., Amazon, EMC, Apple, Cisco, etc.).

In a standard backup environment, an asset (data source or backup client) is assigned a single (primary) backup target where backup data is always written. This provides the highest efficiency as the primary target has knowledge about the backup source based on prior backup operations. In certain situations, however, the primary backup target availability is limited and can cause backups to be exceedingly slow or even fail completely. This can result in compliance issues as certain SLA conditions may not be achieved.

Embodiments of system **100** provide an environment where a backup system can be configured to use a temporary backup target (TBT) on any infrastructure provider (e.g., customer owned, GCP, Azure, AWS, VMware, etc.) on an as-needed basis. The backup system will be able to use an existing TBT or create new instances of temporary backup targets as necessary. The backup system supports a set of rules around the creation, lifetime and deletion of temporary backup targets in order to customize the availability. This will improve overall backup performance and SLA adherence. The backup system also has monitoring and report generation capability to show the history and status of all temporary backup targets in order to provide insights on deployment and provisioning.

A temporary backup target provides a location for backup data to be sent to temporarily in order to minimize data loss due to undesirable availability of a data sources' primary backup target. A TBT may pre-exist or it may be dynamically provisioned on-demand as needed. Backup agents will negotiate with the backup system to identify and find the preferred or most appropriate TBT to send the backup data for a particular or scheduled backup operation. If there is no existing TBT that is be deemed to be sufficient, the backup agent may deploy a new TBT based on established rules. As the future location of a mobile client may be known or anticipated, temporary backup targets may be deployed in advance to avoid the latency occurs when starting up a TBT target on demand. Integration with a user's travel itinerary such as can be done with scheduling or travel software (e.g., Concur and others) can provide dates and locations of where a mobile device may be on any given date.

The backup agent also maintains a set of metadata so that the backup data sent to a TBT will only need to include the data that has been changed since the prior backup. The incremental backup data will later be sent to and consolidated at the primary backup target, at which point recovery operations of these backups can execute. Recovery operations will only be possible from the primary backup target, and therefore data that has not be consolidated will not be available for restoration until it has been consolidated.

FIG. **2** is a block diagram of illustrating functional components of an intelligent destination target selection process, under some embodiments. System **200** of FIG. **2** illustrates the five main components in the architecture of the destination target selection process. Assets **202** are the applications and/or the data and datasets that are being protected. These are the systems, services, or other data sources that contain vital customer assets need to be protected from potential data loss. Examples of these could be file system files, databases, virtual machines, data centers, and so on.

The backup agent will write the data along data path **201** to either the primary backup target **208** or the TBT **212** as directed by backup system **206**. The backup system **206** will communicate via the control path **203** with the primary

backup target **208** and TBT **212** in order to direct the backup agent **204** where to write the data. If it is written to the TBT **212**, it is later consolidated to the primary backup target **208**.

The assets **202** are transmitted through data path **201** to a backup agent **204** ultimately, as directed by control path **203**, to the backup system **206**. The backup agent **204** is responsible for performing the backup and moving the backup data from an asset **202** to the backup storage target, which may be a primary backup target **208**. The agent **204** is a standalone process that can be run on the same system as an asset or can also run on another system. A backup agent **204** will be able to backup one or more assets **202**. The backup agent communicates with the backup system **206** in order to negotiate the preferred backup target. In some situations this could be the primary backup target **208** or a temporary backup target **212**.

The backup system **206** has all the traditional backup system capabilities like managing protection (backup) policies, assets, copies, recovery operations, searches, and so on, as well as viewing monitoring and reporting for alerts and jobs. In addition, the backup system **206** communicates with the backup agent **204** regarding the asset details for the backup operation, the schedule for when to perform a backup, the location for where to send the backup data, and it provides any other configuration information that might be needed by the backup agent.

In addition, a set of rules may be incorporated in the backup system that affects the usage of TBT's **212**. These may apply to a single device or a grouping of devices. Some examples rules are: (1) prohibit the usage of TBT's, (2) only allow TBT's on certain infrastructures or certain availability zones (e.g., AWS only), and (3) only use an existing primary backup target **208**.

The primary backup target **208** is responsible for receiving and storing the consolidated backup data from the backup agent or agents **204**. This will be a fixed backup storage location that will be fairly persistent and not change very frequently. The backup system **206** is responsible for data consolidation from **212** to **208**.

The temporary backup target **212** is responsible for quickly receiving the backup data from a backup agent **204** and then forwarding that data on to the primary backup target **208** after the backup has completed with the backup agent. The lifecycle of a TBT is determined by configuration rules setup in the backup system **206**. These rules are highly flexible to allow creating a TBT **212** as a single backup use or for as long as desired, and even permanently.

For the embodiment of FIG. **2**, the TBT **212** is provided by an infrastructure provider **210**, such as a public cloud provider (e.g., AWS, etc.) or a remote data center owned by the customer. For this use case, having the TBT's lifecycle only be for a single backup could lower or eliminate compute costs. Another use case could be where there is a conference and a group of employees will all be remote for several days, in which a system administrator could setup a co-located TBT, scheduling it to remain up from the start to the end of the conference. Yet another use case is where there may be assets that need a long-living TBT and the lifecycle could be configured appropriately.

The infrastructure provider **210** is used to create and destroy TBT **212** on demand (e.g., as an AWS, Azure, VMware vSphere element). The backup system **206** will be configured with one or more of the infrastructure providers. The backup system **206** can then communicate with the infrastructure provider in order to provision new instances of a TBT.

In most cases a TBT will simply be data storage such as an AWS S3 bucket and therefore will not require any compute resources. The backup system **206** will create an AWS S3 bucket (in the case of an AWS-based TBT) as needed and write asset data **201** to a set of objects within a bucket. TBT's can be destroyed by the backup system **206** only after all data has been consolidated to each asset's respective primary backup target. An empty TBT (one in which all data has been consolidated) may persist if any backup target anticipates future use the TBT as configured in the lifecycle rules.

In an embodiment, TBT's are a type of compute-less storage target, such as AWS S3. Backup agents **204** will examine asset backup metadata in order to determine what new and/or changed data must be sent to a TBT.

The backup operation operates on various metadata elements. In an embodiment, The backup agent **204** has access to backup metadata which may reside on any one of three locations, the asset **202**, the backup agent **204**, or at a backup target (**212** or **208**). It is possible for this metadata to reside in any combination of these three locations. When a backup operation begins, the changed data needs to be determined. There are two primary types of backup metadata that may exist: file-based or hash-based. The metadata in a file-based system requires the backup agent to determine which files have changed since the last backup. Those changed files will be transmitted to the TBT **212**. Consolidation is a simple process where the changed files from the TBT are copied to the asset. A list of deleted files is also transmitted so that they may be removed during consolidation.

The metadata in a hash-based system requires the system to identify newly created hashes. This requires the backup agent to determine the files or objects that have changed since the last backup and then generate hashes from each changed file or object. Each hash will be compared to the set of hashes that have previously been transmitted (such as a hash cache) and only transmit the new hashes and data to the TBT. Metadata about how the hashes relate to each other (e.g., in a Merkle tree) will be retained so that consolidation may properly construct the backup data. As above, a delete list is created, transmitted and processed.

The temporary backup targets **212** can be configured to have a lifecycle that is permanent, semi-permanent, or operational just for a single backup. The backup agent **204** negotiates with the backup system in order to calculate the TBT to be used in order to complete a backup that adheres to the established rules such as the SLA. FIG. **3** is a system diagram **300** illustrating some main components of the deployment and use of a temporary backup target, under some embodiments. As shown in FIG. **3**, the first component **302** is the configuration of a TBT an defining how a backup administrator can configure the lifecycle of the various TBTs and the provisioning rules with the infrastructure provider **210**. The second component **304** is the backup target selection process that happens between the backup agent **204** and the backup system **206**. The third component **306** controls how the backup data is consolidated from the TBT **212** to the primary backup target **208** for permanent storage and recovery purposes.

As shown in system **300** of FIG. **3**, a first component of the destination target selection process **120** is the TBT deployment configuration, **302**. This step configures the on-demand deployment of TBTs in various datacenters. A backup system administrator will have the ability to configure one or more infrastructure providers **210**, which will give the backup system **206** the ability to deploy TBTs **212** as needed. In addition, for scenarios where backup agents

204 are commonly using a temporary backup storage target, the backup manager could retain a TBT to service multiple backups. Other additional rules could be added to allow tuning the lifecycle of the TBTs, by implementing certain policies, such as "destroy TBT if not used within 2 hours," and so on.

The next feature of system **300** involves an automatic negotiation process between the backup agent **204** and the backup system **206** to determine the optimal backup storage target. The negotiation process is triggered either by a scheduled backup, manually by a user, or possibly by other system events like, but not limited to, detecting a new network connection.

FIG. **4** is a state transition diagram **400** that illustrates the process of selecting an optimal backup storage target and transmitting the backup data and consolidating data to the primary target, under some embodiments. Diagram **400** illustrates certain processes performed by and between a backup agent **402**, a backup system **404**, an infrastructure provider **406**, a TBT **408**, and a final backup target **410**.

As shown in in FIG. **4**, the process starts (1) with the backup agent **402** sending a message to the backup system **404** providing geolocation and other potentially useful information like IP, or network connection type (e.g., Cellular, Wired, Personal Wireless, Public Wireless, and so on) in addition to the list of valid infrastructure providers that can be used for creating a TBT.

The backup system **404** (in step **2**) uses the given information from the backup agent in order to calculate a prioritized list of infrastructure provider networks. Various algorithms can be used in order to determine the top infrastructure provider networks to return. One example would be to use geolocation information, and return infrastructure providers that have the closest geographic distance with the asset. The primary backup target will also be included with the first list returned in order to determine if there is enough significant difference in speed from the infrastructure provider networks and the primary backup target. The list of possible network targets to check is then returned to the backup agent **402**, step **3**.

Although embodiments are directed to finding and processing storage targets with based on the closest geographical location, embodiments are not so limited. Such geographic location basically comprises a physical distance between the data asset and a specific target storage location (e.g., data center) as measured in straight-line miles (or similar units). In other embodiments, other measures of data travel may be used, such as direct/indirect routing links, data transmission times, and so on.

FIG. **5** illustrates the selection of an infrastructure provider networks by a backup system for an asset, in an example embodiment. Diagram **500** shows a map of the United States with an asset **502** located in Denver, Colorado. Data Centers ('D') are scattered throughout the country, and the three closest data centers to the asset are located in Kansas, Arizona, Texas, as shown by the circle **504**, and the primary backup target (V) **506** is located in Indiana. Under process **400**, the primary backup target's network information would be sent in the list. The list of possible network targets to check is also returned to the backup agent. FIG. **5** is a visual representation of how the backup system **404** could pick the infrastructure provider networks for the asset **502** in Denver. The three closest data centers in Kansas, Arizona, Texas, and the primary backup target's **506** network information would be sent in the list of step **3**.

After receiving the list, the backup agent **402** performs some throughput and other connection tests with each of the given items in the list, step **4**. The goal with this step is to get the data needed in order to calculate the best possible destination to which to send the backup data. Using the calculations obtained, the backup agent **402** can take the throughput and the backup size to estimate a backup duration for each of the destinations provided in step **3**.

The results are then sent back to the backup system **404** (in step **5**) in order for it to determine if the estimated backup duration is in acceptable limits or if different infrastructure provider networks should be evaluated. This negotiation will be repeated until either a maximum number of negotiation attempts is exceeded or an optimal infrastructure provider is selected. Further details of this negotiation process are outlined in FIG. **6** below.

In step **6**, the backup system **404** gets or creates the TBT, **408**. There are three possible scenarios for selecting the optimal backup target. The first is to select the primary backup target **410**. In this case, no additional work needs to be performed, and the backup agent **402** can send backup data directly to the primary backup target as the final backup target **410**. The second is to select an infrastructure provider **406** that does not have a TBT created. In this case, the backup system **404** will need to provision the necessary TBT **408** using the infrastructure provider's APIs, as shown in step **7** of FIG. **3**. The third is to select an infrastructure provider that already has the needed TBT **408** running.

For the selected TBT or primary backup target, the backup target information will then be sent to the backup agent **402** (step **8**).

In step **9**, the backup agent **402**, using the metadata it manages in order to determine what asset data needs to be sent, will send the full or incremental backup to the backup target given in step **8**. The backup agent **402** then notifies the backup system **404** that it has completed sending the backup data over to the backup target (step **10**).

The backup system **404** then notifies the TBT **408** to move the completed (consolidated) backup data over to the final backup target **410** (step **11**). The TBT then moves the data to the final backup target, or equivalently primary backup target) **410**.

FIG. **6** is a flow diagram illustrating interactions between a backup agent **601** and a backup system **603** for method of negotiating selection of an optimal backup target, under some embodiments.

Process **600** starts with the backup agent **601** obtaining an infrastructure manager list, **602**, which is a list of providers and allowable locations per provider, and that is stored in the backup system. The backup agent **601** sends a message to the backup system **603** providing geolocation, and the backup system **603** uses the given information from the backup agent **601** in order to calculate a prioritized list of infrastructure provider networks. In an embodiment, the infrastructure providers that have the closest geographic distance with the asset are returned in the list, along with the primary backup target

Upon receiving the list of the 'P' and 'D' elements (e.g., as in FIG. **5**), the backup agent **401** performs some throughput and other connection tests **606** for each of the networks provided in the list, and the test results are then sent back **608** to the backup system **603** for receipt **610** in order for it to determine if the estimated backup duration is in acceptable limits or if different infrastructure provider networks should be considered for use. This negotiation will be repeated until either a maximum number of negotiation attempts is exceeded or an optimal infrastructure provider is selected. Thus, as shown in FIG. **6**, in decision block **612**, it is determined whether or not the network throughput for a

given network provider is acceptable based on certain defined threshold values. If not, the process determines whether or not a threshold number of networks has been tested, **614**. If not, the next closest infrastructure provider is processed **604** for the network throughput tests, **606**. If the threshold number of networks has been tested, or if in step **612** the network throughput is acceptable, the process selects the infrastructure provider with the highest throughput, **616**.

Once the highest throughput infrastructure provider has been selected, **616**, the process determines whether or not there are any available backup targets **618**. If not, the process creates a new backup target in the closest infrastructure provider location, **620**. If there is an available backup target available (from **618**) or for a created new backup target (from **620**), the backup target information is sent **622** to the backup agent **602**. The backup agent then starts a backup operation with the given backup target, **624**.

With reference back to FIG. **3**, the final step of process **300** is the consolidation of the backups, **306**. In an embodiment, this is done after the backup agent **204** has completed sending all the required backup data to the TBT **212**. The agent will then be able to mark its backup complete and notify the backup system **206**. The backup system will now orchestrate moving the backup copy stored on the TBT to the primary backup target **208** where it can be consolidated with the other backup copies. This will occur without intervention by the backup agent **204**. After consolidation is complete the normal data protection activities, such as backup restore, replication, and so on, can occur.

FIG. **7** illustrates an example data flow between the asset, TBT, and the final primary backup target for a consolidation operation, under some embodiments. Diagram **700** illustrates an example consolidation of data among a primary backup target **702** in Los Angeles, a TBT **704** in Chicago, and a TBT **706** in New York over a four-day period (Day 0 to Day 3). For this example, on Day 0, the asset is determined to have the best connection to the primary backup target **702**, so the full backup is sent directly there. On Day 1, the asset has moved (e.g., by a user on a laptop) to a new location that has the best connection with the Chicago datacenter **704**. A TBT is automatically provisioned by the backup system in the Chicago datacenter and the backup agent sends an incremental backup there. On Day 2, the incremental backup from Day 1 was moved and consolidated from the Chicago TBT **704** to the primary backup target **702** in Los Angeles. The asset has since moved closer to the New York datacenter and the Backup Agent sent the incremental backup data to the TBT **706** located in the New York datacenter. On Day 3, the Day 2 incremental backup was moved and consolidated and the asset is now back in Los Angeles and the incremental backup can be sent directly to the primary backup target **702**.

Embodiments thus describe a system that automatically determines the ideal backup target for the backup agent to send its backup data. The system will automatically create and destroy temporary backup targets in order to handle the current backup traffic and provide the optimal throughput. The Backup Agent is able to send incremental backups to any TBT which are later consolidated on the primary backup target after the agent has disconnected from the system.

TBT Awareness for Data Restores

As described above, embodiments are directed to systems where an asset (e.g., laptop computer) may choose to send backup data to a temporary backup target (TBT) such that when an asset is first identified and backed up, the data is sent to as primary backup target (PBT), where the PBT is the backup system (software and storage) where the asset was first protected. In this case, the incremental/differential backups will also be sent to this PBT while the asset is in its "home" location. Certain assets, however, such as mobile devices (laptops, tablets, phones, etc.) may not always be in their "home" location, as they are inherently portable and used by mobile users. In this case, sending the backup data to the PBT is not always practical, and future incremental backups may be sent to a TBT which is a simply a data storage system (e.g. Amazon S3). Under the above-described embodiments, restore operations can only operate on data that has landed on the PBT, and data stored on a TBT is not available for restore until this data has been consolidated back to the PBT. This results in restore operations that may not always have access to the most recent backup, which is usually the data that is most useful for restoration.

Embodiments are thus further directed to a system where assets have access to all backups, including the data on the TBT(s) before that data is consolidated back to the PBT. In order to facilitate data backup to a TBT and restore operations from data located on a PBT or TBT or combination of both, a Backup Location Catalog (BLC) is created for each asset and will reside on the asset. In addition a Change Record Catalog (CRC) is created for each TBT backup per asset and each CRC will reside on the asset until the associated data is consolidated back to the PBT.

FIG. **8** illustrates the use of a Backup Location Catalog and Change Record Catalog for awareness of temporary backup targets for data restores, under some embodiments. As shown in FIG. **8**, system **800** comprises an asset **802** having a backup client and console **806**, and local storage **812**. A BLC and CRC **808** are coupled to the backup client and console **806** in the asset.

The asset is coupled to a backup console **814** of the PBT **804** over a command and control path. The backup client and console **806** reside on each client. In addition, another console exists on the PBT **814** which can be used to restore data that was generated by the asset **802** to an alternate location such as when the asset is no longer available as in a disaster recovery situation. For the example of FIG. **8**, data is backed up from local asset storage **812** over data paths to the PBT storage, and one or more TBTs, such as denoted TBT **1** and TBT **2** in system **800**. When a TBT is used as a backup target by an asset, the local backup software **806** will record the location of each backup in the BLC **808** and all changes to the assets' filesystem since the prior backup will be stored in a CRC **808** per TBT backup. Data written to BLC will be transmitted to the PBT storage **816** when a connection from the asset **802** to the PBT **804** is possible.

A copy **818** of the BLC and CRC is maintained on the PBT. A copy of the CRC will also be maintained in each TBT or bucket (e.g., AWS S3 bucket for AWS-based TBT) for each backup written to a TBT (e.g., TBT **1**, TBT **2**) in order to support Disaster Recovery operations.

When a restore operation is initiated, the backup software **806** will pull together all of the backup data and metadata (files/version/dates) from the PBT and TBT backups. While all data will always be available from the local client (assuming continued access to the PBT and all TBTs), the PBT backup console **814** will, in addition to the PBT data, only have access to TBT backups based on the most recently transmitted BLC **808** to the PBT **804**. Until all TBT data has been consolidated, the local (on asset) version of the catalogs will be considered the source of valid data, and the data in the PBT storage **816** or the TBT CRC catalog will only be used for Disaster Recovery operations, such as for data corruption or complete loss of an asset.

During backup operations, data is written from local storage **812** to a PBT **804** or TBT (TBT **1**, TBT **2**). TBT backups update the local and BLC and CRC **808** on the asset **802**. During each TBT backup, the CRC is written to the newly created bucket. BLC changes are transmitted to the PBT when a connection is possible.

In an embodiment, the backup location catalog (BLC) **808** on an asset **802** records the date and location of each backup for an asset. Consecutive backups to the PBT will be combined into a single row in this catalog. Each TBT backup record will be a separate row and will not be merged in this catalog. Consolidation will remove TBT entries and update the oldest PBT entry until all data has been consolidated from the TBT(s) to the PBT.

FIG. **9** is a table **900** that illustrates a portion of a backup location catalog, under an example embodiment. Each row in this catalog consists of date/timestamp in column **901** and a backup location in location column **902**. The location column begins with a PBT row that means that the backup resides in its normal backup format on the assets' primary backup target and will be represented in the form PBT:<url> where URL (uniform resource locator) is the network address of the PBT server. All other (TBT) backup rows identify where a dump of assets' files are located with each row representing an additional backup. As shown in the example, the form of those locations are recited as: <Provider>:<region>@<storageType>:<assetName>:<date>. As the asset name will always be unique across an organization, a namespace (such as an AWS bucket name) will be composed of the assetName and date. All data per backup per asset will be sent to a separate bucket. During each backup operation, the BLC **808** will be modified and stored locally on the asset **802**. The BLC will also be sent to the PBT **804** when a connection is available. Note that an asset with no TBT backups (including after all TBT backups have been consolidated to the PBT) will not have a BLC.

Table **900** is provided for purposes of illustration only and embodiments are not so limited. A backup location catalog can be implement using many other formats and data content.

With respect to the temporary backup target (TBT), each TBT backup bucket will contain the contents of each modified or created file since the prior backup. Each created/modified file is stored along with a fully qualified path as known by the asset. As S3 and other TBT provider (e.g. Azure Storage) typically provide object storage and not a hierarchical file system, the fully qualified (hierarchical) path may be emulated via the object name. Each file is stored as a single object. Various different file naming conventions can be used. In addition, various different directory hierarchies and file system conventions can be used to implement a TBT bucket under different embodiments. For example the file degAlertsAll.go in a particular directory tree on the asset can have an object named "/c/Data/UI/deg/degAlerts/degAlertsProducts/degAlertsAll/degAlertsAll.go," and the contents of this object will be the contents of the file from the asset at the relevant point in time.

With respect to the Change Record Catalog (CRC), for each TBT backup, a change record catalog will exist in each TBT bucket in addition to being stored locally on the asset. It will contain a list of all changes to the filesystem including some system level information. The CRC contains enough information for the backup clients to present to the user the state of an asset at any point in time. This will be used by restore operations to locate the files to be restored or assist in a disaster recovery situation. For example, a CRC file may be named deltas.json and may contain file information included files created/modified/deleted/moved, location information, directory links to changed file data, and so on. Various different file naming conventions can be used, along with various different directory hierarchies and file system conventions to implement a CRC file, under embodiments.

FIG. **10** is a flowchart that illustrates a method of providing intelligent target selection for portable assets using awareness of temporary backup targets, under some embodiments. Such a process provides access by assets to all backups before that data is consolidated back to the PBT to facilitate backup and restores when an asset physically moves from a home environment where the PBT may be located. As shown in process **950**, and as described above the system maintains a BLC for each asset and a CRC on each asset, **952**. Backup data is then sent from the asset to the PBT and one or more TBTs, **954**. The TBT stores only incremental data, while the PBT will have a full and usually most incremental backups, as the TBT is only used while an asset is away from it "home" location. The asset backup software will then record the location of each backup in the BLC and all changes to the assets' filesystem in the CRC for a respective TBT backup, **956**. Data written to the BLC will be transmitted to the PBT storage when a connection is possible, **958**. A copy of the CRC will also be maintained in each TBT or bucket for each backup written to a TBT, **960**.

During backup operations, **962**, data is written from asset local storage to a PBT **804** or TBT, and TBT backups update the local and BLC and CRC on the asset.

During restore operations **964**, the backup software evaluates (pulls together) all of the backup metadata from the PBT and TBT backups and determine which data is to be pulled from the PBT and which data should be pulled from a TBT The PBT can access the data stored in TBT backups based on the most recently transmitted BLC. This allows data assets to have access to all backups including data on a TBT before the data is consolidated back to the PBT so that restores can operate on data before it has landed on the PBT.

In general, restores evaluate the metadata to determine what data is needed, and only pull that data from the PBT and/or TBT to restore the asset to the desired state as specified in the backup console by the user (e.g., yesterday's data, last week's data, etc.). The consolidation step is a different process where data on the TBTs are moved to the PBT.

In an embodiment, restore operations **964** can be initiated from either backup console **806** or **814** on the asset **802** or PBT **804**, respectively. Either the local console or the PBT console will be able to restore any retained version of any file assuming connectivity to the PBT **804** and all TBTs (e.g., TBT **1**, TBT **2**). In the case of the PBT, the backups available to restore will include the PBT data and the TBT backups where the BLC **808** data was received. In the case of disaster recovery, the PBT **804** will search all known TBTs and look for backups that belong to the asset. The latest version of each file across the PBT and all found TBTs will be used to create a new asset from all available backup data for the "lost" asset. Likewise, the asset local console **806** will be able to restore any retained version of any file assuming connectivity to the PBT and all TBTs.

In order to perform a restore (from either console) system will combine the oldest PBT backup records and the CRC data from the TBT backups to present the user with backups from all points in time, as limited only by the retention policy for the asset. A synthetic catalog will be built using the metadata from the PBT backup and the CRC records. For each chosen file, the system will determine the appropriate data source (PBT or TBT) based upon the version chosen in

the restore console. Restores of PBT versions of files can use deduplication technology to efficiently retrieve only the necessary data, while restores of TBT versions will require a full file moves. This data egress event from a public cloud provider will generally incur a cost.

Consolidation is the process of moving data from Temporary Backup Targets to the Primary Backup Target. This is always done starting with the oldest TBT entry in the catalog to the most recent. Consolidation of a TBT backup involves moving the data from the TBT location to temporary storage on the asset and then running the normal PBT backup so that it will reside in the PBT in its native format (e.g. DeDup). The temporary storage location will need to be remapped to the "true" location of the data so that the backup process can properly add this new data to asset's backups. In addition to processing the created and modified files from a TBT, the CRC must be processed so that the assets' backup also correctly handle files that were moved or deleted. When this consolidation is complete, the TBT bucket can be deleted and the BLC can be updated so that the oldest PBT entry date is updated and the oldest TBT row is removed.

Restores from a TBT

As described above, embodiments of the data protection system use temporary backup targets to hold backup data when an asset stores some incremental backups on an alternate backup target. In such systems, data is restored only after it is consolidated to the primary backup target. Further embodiments improve the system by allowing restores from backup data that is stored in either (or both) the primary and temporary backup targets, thus allowing restores regardless of where the backup data resides.

As shown in FIG. **1**, system **100** includes a processing component **121** for executing data restores from temporary backup targets. This process uses a file view of backup data. Other views such as block-based and other formats are also possible. Backup datasets can be stored in various different formats, such as object-based, block-based, file-based, or other filetypes. Of these formats, file-based storage for a file type hierarchy is usually preferred as this typically matches the user view of a filesystem. For this embodiment, the backup data files are broken up into chunks and each chunk holds a portion of the file, which may be on the order of 20K-40K bytes in size depending on the chunking algorithm and data. A hashing algorithm such as SHA-1 or SHA-256 will represent the data in a much smaller number of bytes (typically less than 1% of the chunk size). There are two types of hash records, one that contains the hash of each file data chunk, and the other that represents a set of hashes.

A Merkle tree is used to hold the hashes for each file so that data restore workflows (e.g., full restores, restoring a file/directory to a prior state, etc.) are enabled while minimizing the amount of storage required to hold the backup data. In the case of a single backup target, each piece of data is held on the backup target. In an environment where multiple backup targets are used, a backup target location value is added to non-data chunk hash records and can be used to identify where any piece of backup data is located so that restore operations can occur when the backup data is spread across multiple backup targets.

FIG. **11** illustrates some example Merkle tree representations of different backups with no temporary backup target, under some embodiments. The example Merkle tree **1102** represents a file backed up initially (for data chunks respectively hashed as "Hash **1**," "Hash **2**," and "Hash **3**) where only a single backup target and no temporary backup target is used. It should be noted that for these figures, only the first three data chunk records are shown, however every low level hash may represent a single data chunk or could be a hash of multiple chunks (also known as a composite chunk).

FIG. **11** shows the evolution of the Merkle tree for the case of a single file stored over three backups, each backup adds additional data. As shown in FIG. **11**, upon the first backup ("Backup X") of a number (N) of backups, the Merkle tree **1102** contains three chunks of data represented by hash **1**, hash **2** and hash **3** respectively. The file itself is represented by the top-level hash **4**, which is the hash of these three data chunk hashes.

Tree **1104** illustrates a next backup (Backup X+1) as the Merkle tree is extended to include data chunk **5** and data chunk **6**. Hash **7** is the hash of these two new chunks and the entire file is represented by hash **8**, which is the hash of hash **4** and hash **7**.

Tree **1106** illustrates a subsequent backup (Backup X+2) as the Merkle tree is changed to reflect that the data within data chunk **6** is modified and the file is extended to include data chunk **10** and data chunk **11**. Hash **9** now represents the unchanged data from Backup X (hash **4**) and Backup X+1 (hash **5**). Hash **12** now represents the data from backup X+2 which is the modified data chunk **6** (data chunk **6'**) plus the two new chunks. Finally, the entire file is represented by hash **13**, which is the hash of hash **9** and hash **12**.

FIG. **12** is a table **1202** illustrating a tabular composition of the example Merkle trees of FIG. **11**. As shown in FIG. **12**, table **1202** contains entries for the Backup, Backup Root Hash, Chunk Hashes, and Intermediate Hashes. This table illustrates the case of Merkle tree representations without any location identifier, such as may be the case when no temporary backup target is used.

For embodiments in which one or more temporary backup targets (TBTs) are used, and enhanced Merkle tree containing location information is used, and the table is modified accordingly. FIG. **13** illustrates a table **1302** for an enhanced Merkle tree with location information, under some embodiments. As shown in FIG. **13**, in the case of multiple backup targets, a catalog of target IDs and locations is maintained, and table **1302** represents an example backup target table.

With respect to the example of FIG. **13**, there will be a small number (typically less than 32) backup targets per asset, and ID 0 is always assigned to be the primary backup target. The backup URL, which denotes the network location of the backup storage, is provided in a format specific to the provider and repository store, and may be provided as any appropriate uniform resource locator (URL) or similar string.

In an embodiment, the temporary target restoration process **121** adds a location value to each hash record except for those that only refer to a data chunk. As non-chunk hashes may reference data that resides on multiple backup targets, the location ID is a bitmap which indicates all the backup targets that hold the data for any non-data chunk hash. Each bit in this location ID bitmap that is turned on corresponds to the IDs in the backup target table **1302**. For the example of FIG. **13**, a location ID value of 1 refers to the primary (ID 0) as bit 0 is turned on. This is always a reference to the primary backup target. A location ID value of 4 (bit 2 is on) in this example refers to data held on the London temporary backup target. A value of 5 would then indicate that some data is on the Primary target and other data is in London.

FIG. **14** shows the evolution of the Merkle trees of FIG. **11** for the case of a single file stored over three backups for an embodiment using multiple backup targets. With the addition of multiple backup targets, the first level composite hashes (one level up from the data hashes) must all come

from the same backup target. This means that exactly 1 bit will be turned on in the location mask (value of 1, 2, 4, 8 or any other power of 2). This will enable the restore workflow to be optimized. As can be seen in FIG. **14**, the creation of composite hash **10** and the different composite hash **9** reflect this requirement. Whereas, previously data hash **5** was referenced in composite hash **9**, using multiple backup targets as shown in FIG. **11**, composite hash **9** only points to data hash **5** and the new hash **10** brings together the data from backup X (stored on the primary) and X+1 (stored in Virginia).

As shown in FIG. **14**, each non-data chunk hash record (e.g., "Hash **4**") will have a location indicator appended as a field, **1401**. When the underlying data resides on multiple backup targets (e.g., hash **10** and hash **14** in Merkle tree **1406**), the location ID will have 1 bit turned on for every backup target needed to access the data represented by a hash. This can be seen by looking at the location ID value for hash **10** and hash **14**. During backup for assets that have TBT enabled, the location ID identifies all of the backup targets that are needed to reconstruct the related portion of the file.

FIG. **15** is a table **1502** that illustrates backup records for multiple backup targets with attributes of the enhanced Merkle tree after Backup X+2 of FIG. **14**. As can be seen in FIG. **15**, for the second subsequent backup (Backup X+2), the backup root hash is now 14 (as opposed to **13** in table **1202**), and **13** becomes an intermediate hash.

FIG. **16** is a flowchart that illustrates a method of performing backup and restores using location information for temporary backup targets, under some embodiments. In general, backup workflows operate nearly identically to a system where only a single backup target exists, except for the addition of a location value and any needed extra hash records being generated, step **1602** (and as shown in the example of FIG. **15**).

As shown in process **1600**, the restore workflow, however, changes significantly in the case of temporary backup targets. A restore operation will begin by presenting all of the backups available, **1604**. As backups may be distributed across multiple targets and some targets may not be accessible for various reasons at any point in time, a list of backups along with availability status can be shown. In order to know which backups are available, the location value of the backup root hash record is examined and the related backup targets backup URL is checked, **1606**. The backup availability will be based on the location value in the backup root hash record.

FIG. **17** illustrates a table **1702** showing backup URLs related to a backup, under some embodiments. As shown in table **1702**, certain values are provided for the fields: Backup Root Hash, Location Value, and Backup URLs. Each backup operation of the series of backups X to X+n, has a root hash location value and corresponding backup URLs, as shown in the example of FIG. **17**. In order for a backup to be available, the backup URL for all of the required locations must be available.

During a restore, the hashes of the specific version of a file are identified, **1608**. The lowest level, non-data hashes are a hash of data chunk hashes that exist on a single backup target. For these hash, the location value maps to exactly one location ID.

A restore operation is then performed through the substeps **1610**:

1. Get the Data Chunk Hashes for a version of a file (Cv: Chunks per Version)
2. Compute/determine the Chunks that exist locally on the asset (Cl)
3. Find list of Chunks that are missing on the asset by computing (Cm=Cv−Cl)
4. Break up Cm by Backup Target ID (Cm0, Cm1, . . .) using the Location Value
5. Retrieve the data from each Backup Target (e.g. −Cm0)
6. Construct the file using the retrieved data and any local data as appropriate

In step **1612**, a cost estimation is performed. If a restore cost exceeds a preset threshold (e.g., $1.00), then the user will be given a cost estimate and the option to cancel the restore. The cost is computed using the number of chunks to retrieve and an estimate of the transfer size which is approximately 22K bytes per chunk. Each chunk will cost one GET plus the fee to transfer 22 KB. In the above example, the cost per chunk is approximately $0.004 ($0.00400198) or roughly 4 cents for 22 MB.

The data is then consolidated, **1615**. When data is consolidated from a temporary backup target to the primary backup target, the location value must be updated so that the data chunk hash location ID is set to 1 (for ID 0) and all hash records up the tree are modified appropriated. For example, when Backup X+1 is consolidated, the location ID in hash **7** and hash **8** are set to 1.

As described, embodiments of the temporary target restore process provide a system that allows incremental backup data to distributed across multiple backup targets. The system further enables restore workflows of data distributed across multiple backup targets, and provides feedback to a user regarding the estimated cost to recover data.

System Implementation

Embodiments of the processes and techniques described above can be implemented on any appropriate backup system operating environment or file system, or network server system. Such embodiments may include other or alternative data structures or definitions as needed or appropriate.

The processes described herein may be implemented as computer programs executed in a computer or networked processing device and may be written in any appropriate language using any appropriate software routines. For purposes of illustration, certain programming examples are provided herein, but are not intended to limit any possible embodiments of their respective processes.

The network of FIG. **1** may comprise any number of individual client-server networks coupled over the Internet or similar large-scale network or portion thereof. Each node in the network(s) comprises a computing device capable of executing software code to perform the processing steps described herein. FIG. **8** shows a system block diagram of a computer system used to execute one or more software components of the present system described herein. The computer system **1000** includes a monitor **1011**, keyboard **1017**, and mass storage devices **1020**. Computer system **1005** further includes subsystems such as central processor **1010**, system memory **1015**, I/O controller **1021**, display adapter **1025**, serial or universal serial bus (USB) port **1030**, network interface **1035**, and speaker **1040**. The system may also be used with computer systems with additional or fewer subsystems. For example, a computer system could include more than one processor **1010** (i.e., a multiprocessor system) or a system may include a cache memory.

Arrows such as **1045** represent the system bus architecture of computer system **1005**. However, these arrows are illustrative of any interconnection scheme serving to link the subsystems. For example, speaker **1040** could be connected

to the other subsystems through a port or have an internal direct connection to central processor **1010**. The processor may include multiple processors or a multicore processor, which may permit parallel processing of information. Computer system **1000** is just one example of a computer system suitable for use with the present system. Other configurations of subsystems suitable for use with the described embodiments will be readily apparent to one of ordinary skill in the art.

Computer software products may be written in any of various suitable programming languages. The computer software product may be an independent application with data input and data display modules. Alternatively, the computer software products may be classes that may be instantiated as distributed objects. The computer software products may also be component software.

An operating system for the system **1005** may be one of the Microsoft Windows®. family of systems (e.g., Windows Server), Linux, Mac OS X, IRIX32, or IRIX64. Other operating systems may be used. Microsoft Windows is a trademark of Microsoft Corporation.

The computer may be connected to a network and may interface to other computers using this network. The network may be an intranet, internet, or the Internet, among others. The network may be a wired network (e.g., using copper), telephone network, packet network, an optical network (e.g., using optical fiber), or a wireless network, or any combination of these. For example, data and other information may be passed between the computer and components (or steps) of the system using a wireless network using a protocol such as Wi-Fi (IEEE standards 802.11, 802.11a, 802.11b, 802.11e, 802.11g, 802.11i, 802.11n, 802.11ac, and 802.11ad, among other examples), near field communication (NFC), radio-frequency identification (RFID), mobile or cellular wireless. For example, signals from a computer may be transferred, at least in part, wirelessly to components or other computers.

In an embodiment, with a web browser executing on a computer workstation system, a user accesses a system on the World Wide Web (WWW) through a network such as the Internet. The web browser is used to download web pages or other content in various formats including HTML, XML, text, PDF, and postscript, and may be used to upload information to other parts of the system. The web browser may use uniform resource identifiers (URLs) to identify resources on the web and hypertext transfer protocol (HTTP) in transferring files on the web.

For the sake of clarity, the processes and methods herein have been illustrated with a specific flow, but it should be understood that other sequences may be possible and that some may be performed in parallel, without departing from the spirit of the described embodiments. Additionally, steps may be subdivided or combined. As disclosed herein, software written in accordance certain embodiments may be stored in some form of computer-readable medium, such as memory or CD-ROM, or transmitted over a network, and executed by a processor. More than one computer may be used, such as by using multiple computers in a parallel or load-sharing arrangement or distributing tasks across multiple computers such that, as a whole, they perform the functions of the components identified herein; i.e., they take the place of a single computer. Various functions described above may be performed by a single process or groups of processes, on a single computer or distributed over several computers. Processes may invoke other processes to handle certain tasks. A single storage device may be used, or several may be used to take the place of a single storage device.

Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise," "comprising," and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say, in a sense of "including, but not limited to." Words using the singular or plural number also include the plural or singular number respectively. Additionally, the words "herein," "hereunder," "above," "below," and words of similar import refer to this application as a whole and not to any particular portions of this application. When the word "or" is used in reference to a list of two or more items, that word covers all of the following interpretations of the word: any of the items in the list, all of the items in the list and any combination of the items in the list.

All references cited herein are intended to be incorporated by reference. While one or more implementations have been described by way of example and in terms of the specific embodiments, it is to be understood that one or more implementations are not limited to the disclosed embodiments. To the contrary, it is intended to cover various modifications and similar arrangements as would be apparent to those skilled in the art. Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements.

What is claimed is:

1. A computer-implemented method of restoring data from one or more temporary backup targets, comprising:

accessing data of a plurality of files backed up in a series of periodic backups, wherein each backup of the periodic backups is referenced by a hash value that indicates a location of a temporary backup target of the one or more temporary backup targets storing a respective backup of the periodic backups;

examining and checking the location of the temporary backup target, the checked location storing a specific version of a file of the plurality of files;

identifying hashes of the specific version of the file for the checked location;

performing a restore operation on data chunks referenced by the identified hashes, wherein some data chunks may be stored locally on a primary backup target and others may be retrieved from the temporary backup target.

2. The method of claim **1** wherein the restore operation comprises:

obtaining the hashes of the data chunks;

computing hashes of locally stored data chunks;

accessing a list of missing data chunks;

breaking a missing data chunk by backup target ID;

retrieving the missing data chunk from the backup target corresponding to the backup target ID; and

constructing the file to be restored using the retrieved and locally stored data chunks.

3. The method of claim **1** further comprising:

defining a cost threshold for the restore operation; and

determining if the restore operation exceeds the cost threshold, and if so, providing a user with an option to cancel the restore operation, otherwise proceeding with the restore operation, and wherein the cost threshold computed by factoring a number of data chunks to retrieve and an estimate of a transfer size of the backup.

4. The method of claim **1** further comprising storing hashes of each file of the plurality of files in a Merkle tree is used to enable data restore workflows and minimizing an amount of storage required to hold backup data.

5. The method of claim 4 wherein a lowest level of the Merkle tree comprises hashes of data chunks of the backup, and higher levels of the Merkle tree contain hashes of immediately lower levels of the Merkle tree.

6. The method of claim 5 further comprising adding a backup target location value to non-data chunk hash records in the higher levels to identify where any piece of backup data is located so that restore operations can occur when the backup data is spread across multiple backup targets.

7. The method of claim 6 further comprising:

consolidating data chunks from the temporary backup target to the primary backup target;

updating the location of the consolidated data chunks; and

modifying remaining hash values in the Merkle tree for the consolidation.

8. The method of claim 1 wherein the location information comprises a Uniform Resource Locator (URL).

9. The method of claim 8 further comprising storing the URL in a database associating the backup target location with one of a primary or temporary backup target type and corresponding location ID.

10. The method of claim 1 wherein the database further stores cost information for read operations from a corresponding backup target and transfer costs from the corresponding backup target for cost estimations of the restore operation.

11. The method of claim 1 wherein each backup is performed by a backup operation comprising:

selecting an optimum destination storage for mobile data assets, comprising:

automatically determining a primary backup target to send backup data of the data asset;

sending incremental backups of the data asset to the primary storage target and the temporary backup targets based on movement of the data asset from one geolocation to another geolocation;

first maintaining, in the data asset, a backup location catalog (BLC) and a change record catalog (CRC);

second maintaining, in a temporary backup target, a copy of the CRC for a backup written to the temporary backup target;

updating the BLC and CRC in the data asset upon the backup to the temporary backup target; and

combining, during a restore operation, data and metadata of the backup from the primary backup target and the temporary backup target, wherein the updating allows the primary backup target to access the temporary backup based on a most recent updated BLC.

12. The method of claim 1 wherein each backup is performed by a backup operation comprising:

initiating a backup of the data to a backup system through a backup agent;

automatically determining a storage target for the backup agent to send the data;

automatically creating and destroying the temporary backup targets in order to accommodate current backup traffic levels and to provide optimal throughput of the backup data to the storage target;

sending, from the backup agent, incremental backups of the data asset to one or more temporary backup targets based on movement of the data asset from one geolocation to another geolocation; and

transferring the incremental backups from the one or more temporary backup targets for consolidation and storage on the storage target.

13. A computer-implemented method of backing up and restoring data in a deduplication backup system, comprising:

initiating a backup of a data asset to the backup system through a backup agent;

automatically determining a storage target for the backup agent to send backup data of the data asset;

automatically creating and destroying temporary backup targets in order to accommodate current backup traffic levels and to provide optimal throughput of the backup data to the storage target, wherein each temporary backup target is referenced by a unique locator ID;

sending, from the backup agent, incremental backups of the data asset to one or more temporary backup targets based on movement of the data asset from one geolocation to another geolocation;

transferring the incremental backups from the one or more temporary backup targets for consolidation and storage on the storage target, wherein the backups comprise data chunks referenced by respective hashes;

checking, upon a restore operation, the location of a temporary backup target of the one or more temporary backup targets, the checked location storing a specific version of a file of the files;

identifying hashes of the specific version of the file for the checked location; and

performing a restore sequence on data chunks referenced by the identified hashes.

14. The method of claim 13 further comprising storing hashes of the data chunks in a Merkle tree is used to enable data restore workflows and minimizing an amount of storage required to hold backup data.

15. The method of claim 14 wherein a lowest level of the Merkle tree comprises hashes of data chunks of the backup, and higher levels of the Merkle tree contain hashes of immediately lower levels of the Merkle tree.

16. The method of claim 15 further comprising adding a backup target location value to non-data chunk hash records in the higher levels to identify where any piece of backup data is located so that restore operations can occur when the backup data is spread across multiple backup targets.

17. The method of claim 13 wherein the restore sequence comprises:

obtaining the hashes of the data chunks;

computing hashes of locally stored data chunks;

accessing a list of missing data chunks;

breaking a missing data chunk by backup target ID;

retrieving the missing data chunk from the backup target corresponding to the backup target ID; and

constructing the file to be restored using the retrieved and locally stored data chunks.

18. The method of claim 13 further comprising:

defining a cost threshold for the restore operation; and

determining if the restore operation exceeds the cost threshold, and if so, providing a user with an option to cancel the restore operation, otherwise proceeding with the restore operation, and wherein the cost threshold computed by factoring a number of data chunks to retrieve and an estimate of a transfer size of the backup.

19. The method of claim 18 further comprising:

consolidating data chunks from the temporary backup target to the storage target;

updating the location of the consolidated data chunks; and

modifying remaining hash values in the Merkle tree for the consolidation.

20. A non-transitory computer program product embodied as a tangible media containing programming code which, when executed by a processor, cause the processor to perform a method of restoring data from one or more temporary backup targets, comprising:

accessing data of files backed up in a series of periodic backups, wherein each backup of the periodic backups is referenced by a hash value that indicates a location of a temporary backup target of the one or more temporary backup targets storing a respective backup of the periodic backups;

examining and checking the location of the temporary backup target, the checked location storing a specific version of a file of the files;

identifying hashes of the specific version of the file for the checked location;

performing a restore operation on data chunks referenced by the identified hashes, wherein some data chunks may be stored locally on a primary backup target and others may be retrieved from the temporary backup target.

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